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SANTA CLARA VALLEY WATER REUSE STUDY

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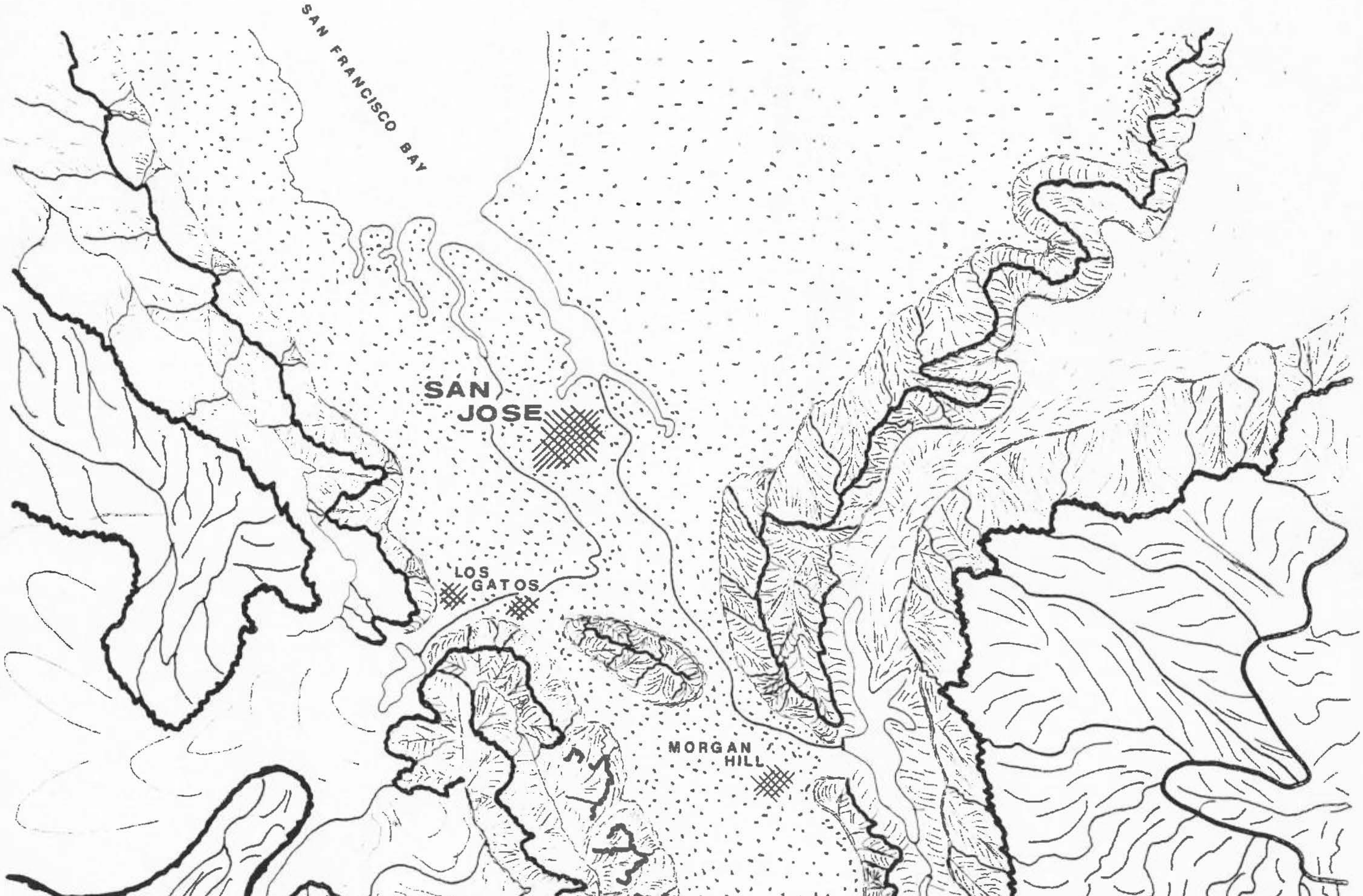

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SANTA CLARA VALLEY WATER REUSE STUDY
PHASE 1B

Central District

June 1983

FOREWORD

The Santa Clara Valley Water Reuse Study was conducted to evaluate the feasibility of reclaiming waste water to augment water supplies in Santa Clara Valley. The waste water would be obtained from the treatment facilities located in San Jose.

Primary funding for this study (75 percent) was provided by an Environmental Protection Agency (EPA) planning grant. The State Water Resources Control Board (State Board) funded 12-1/2 percent of the study; the Department of Water Resources (DWR) funded 9 percent; and the Santa Clara Valley Water District (SCVWD) funded the remainder.

The grant was administered for EPA by the State Board. SCVWD was the grant recipient and the lead agency for the study. DWR did considerable work for SCVWD under an interagency agreement.

The Phase IA report, published in December 1980, addressed the different aspects pertaining to surface delivery of reclaimed water for irrigation. This Phase IB report evaluates the feasibility of recharging the Santa Clara Valley ground water basin with reclaimed water.

Members of the study staff appreciate the members of the study's Water Reuse Advisory Committee, whose helpful suggestions and continued interest in the study have greatly aided the progress of this work.

Robert G. Potter

Robert G. Potter, Chief
Central District

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Chapter 1. INTRODUCTION

The terms waste water reclamation and reuse are largely self-explanatory. Waste water reclamation refers to treatment of waste water to enable further use; reuse refers to using this effluent rather than discharging it into a saline water body such as a bay or ocean. In 1978, the U. S. Environmental Protection Agency gave notice that within three years, some 40,000 industrial plants must pretreat wastes to remove chemicals not well removed by sewage plants /1/. The pretreatment program is intended to result in cleaner effluent and sludge than at any time in the past. As a result of continued pollution control efforts, reclaimed water produced from waste water today is in some respects cleaner than potable water used in the past /2/.

The high quality effluents from modern treatment facilities make waste water available for reuse. Some possible uses are:

° Ground water recharge.
° Land application for irrigation.
° Industrial process water.
° Impoundment for recreation facilities.

When ground water recharge is achieved by means other than natural, it is known as artificial recharge. Artificial recharge is a method of augmenting an existing ground water supply. The two main techniques for this augmentation are surface spreading and direct injection. Surface spreading is the spreading of water on the surface of the soil. The water then percolates downward and recharges, or augments, an aquifer. Direct injection is the pumping of water into abandoned wells or wells designed specifically for artificial recharge. Because of the expense of injection, the use of injection wells is largely confined to those areas where surface spreading is not feasible due to the presence of impermeable clay layers overlying the water-bearing deposit or to urban areas where the cost of land is prohibitive.

Determination of whether artificial ground water recharge is physically practicable in a specific area requires an analysis of the geologic nature and structure of the area. In this regard, no two projects are the same because the technique of recharge must be tailored to the needs of the specific area. Regardless of location, a successful recharge project will have these characteristics /3/:

° An effective recharge system.

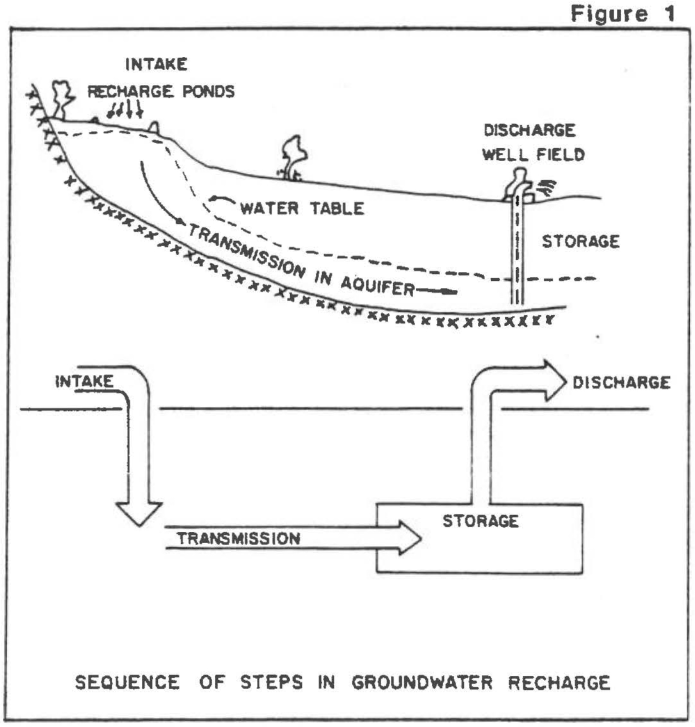
° Effective transmission to the point(s) of discharge or extraction.

° Storage between the points of recharge and extraction.

° An effective extraction system.

These points are illustrated in Figure 1.

Figure 1



SEQUENCE OF STEPS IN GROUNDWATER RECHARGE

This report investigates ground water recharge as a reuse opportunity by summarizing experience gained in demonstrations and operating projects in the United States and abroad. This information is then used to assess health concerns related to water reuse for municipal supply.

The effectiveness of various levels of treatment and the problems arising in control of various types of contaminants are reviewed, with emphasis on the viruses and trace chemical contaminants. The capacity of soils to remove contaminants is also examined. Potential sources of reclaimable waste water are identified. Alternative potential reclamation projects are described and evaluated.

The scope of this study was restricted to an analysis of potential reuse projects using waste water of the San Jose-Santa Clara Water Pollution Control Plant. Therefore, the study did not consider other potential project concepts such as construction of new waste water treatment facilities near areas of potential reclaimed water markets. Project alternatives beyond the scope of this study may prove worthy of further study, as major costs of water conveyance might thereby be minimized.

Conclusions

The most promising alternative for reclaiming and using waste water from the San Jose-Santa Clara Water Pollution Control Plant would be to inject it into the main aquifer of the Santa Clara Valley basin, where it would be available for all water uses. The injection site would be located near the treatment plant, in an area of high water use. To make the water as safe as technically feasible for injection and eventual extraction as drinking water, additional treatment consisting of activated carbon adsorption and reverse osmosis would be required. The cost of the reclaimed water, including injection costs, would range from $360 to $430 per acre-foot. This cost would not compare favorably to the cost for water from the San Felipe Project, but may be comparable to the cost of future water supplies of the State Water Project. The project might be economically viable if, at a future date, the State Water Project were a participant.

While economic feasibility is an important aspect of the overall feasibility of a reclamation project in the Santa Clara Valley, there are other important aspects. First, there are now no Federal or State water quality standards for reclaimed water to be used as a drinking water supply. Standards would have to be established through the California Department of Health Services in order for a project to be possible. Second, a project to be implemented must be demonstrated to be safe and must be acceptable to the ultimate consumers of the water. This demonstration and acceptance would require pilot studies and a consumer education program.

A second alternative studied was the feasibility of recharging the Santa Clara Valley basin through surface spreading. This alternative was found to be economically infeasible, primarily because of the high cost of conveying the water to a suitable location for spreading.

The third alternative studied was a project to renovate and use the presently saline semiperched water zone overlying the main drinking water aquifer of the Santa Clara Valley basin. While conceptually appealing, this alternative has technical problems that make it difficult to predict the physical and economic effectiveness of renovating the aquifer.

Recommendations

The reclamation project alternative to inject reclaimed water into the main drinking water aquifer of the Santa Clara Valley basin appears to have potential as an economical and safe project. Further study should be undertaken to determine whether the State Water Project can be a participant in the reclamation project. Participation by the State Water Project would be in accordance with the Department of Water Resource's December 1982 "Revised Guidelines on Funding Local Water Supply Projects for Inclusion in the State Water Project".

Additional study should be postponed until the Department of Water Resources has identified fresh water supply alternatives and has formulated accurate cost estimates for these alternatives. Only then will a valid cost comparison be possible.

When additional study is undertaken, a baseline epidemiologic study should be included to evaluate the health of consumers that may ultimately use the water. If a project is implemented, subsequent evaluations should be made at intervals of ten years to verify absence of adverse health effects.

Chapter 2. GROUND WATER RECHARGE PROJECTS

Treated effluent must be viewed as a resource opportunity rather than a disposal problem. There are many examples of successful waste water reuse projects. This study will draw heavily upon the experience of other projects in evaluating potential waste water reuse in the Santa Clara Valley. This chapter describes recent international, national, and local reclamation and recharge projects.

Most of the projects discussed are not directly applicable to consideration of recharging waste water for use as drinking water. The Windhoek Reclamation Plant in Namibia, for instance, does not involve ground water recharge at all, although the plant directly recycles waste water for domestic use. Many of the ground water recharge projects discussed here are intended for nonpotable use. Therefore, the water quality criteria applicable to those projects would not apply to potable use. The intent of this chapter is to develop a general perception of the types of reclamation projects that have been successful and to use that information as a framework for developing a project in the Santa Clara Valley.

International Ground Water Recharge Projects

Two waste water reclamation projects outside the United States have been studied and are described below.

The Dan Region Project, Israel

The Dan Region Project is the largest and most advanced waste water reclamation and reuse project in Israel. It provides advanced treatment, ground water recharge, and indirect reuse of municipal waste water for the Tel Aviv metropolitan area (population 1,000,000). The following summary is taken from the many recent articles on this project /4,5,6,7/.

The project was conceived in about 1966, but full-scale reclamation did not begin until 1976. Numerous laboratory experiments on municipal waste water and a pilot-scale study were carried out prior to full-scale implementation of the project.

The original idea was to produce an effluent that could be reused indirectly (via ground water recharge) for all purposes, including domestic consumption.

In 1975, a different approach was adopted -- indirect, nonpotable reuse. The limited-use approach required conversion of the water supply network to a dual system to convey potable water and reclaimed water separately. Indirect potable reuse was rejected because of inconclusive data on long-term accumulation of some substances in humans and association of reclaimed water with carcinogenic and mutagenic effects.

Stage I of the Dan Region Project has been in full operation since 1976 and now serves a population of about 250,000 /4/. Waste water from the Tel Aviv area undergoes three major treatment processes prior to ground water recharge by means of spreading basins:

1. Biological treatment in recirculated oxidation ponds.

2. High lime-magnesium treatment in a sludge-blanket reactor clarifier.

3. Detention in polishing ponds for ammonia-stripping, natural recarbonation, and additional purification.

The success of ground water recharge with municipal effluent depends on a series of factors:

- The quality of recharge water.
- Recharge-recovery operations.
- Infiltration rates.
- Ground water monitoring to evaluate movement and changes in the quality of the resulting mixture.

The effect of percolation through the upper 6 feet of soil on effluent quality is moderate and fluctuating for most parameters /7/. The pH, alkalinity, and Langelier Saturation Index are improved because of percolation.

The transport of recharged effluent through the aquifer produced the following results:

- Constituents that are affected only by dilution and are not removed by the soil (i.e., chlorides) will concentrate in the aquifer until levels similar to those of the recharged water are reached (short transition period).
- Constituents removed by adsorption (boron) or ion-exchange (sodium) will concentrate in the aquifer until levels there are the same as in effluent (same as above, but with longer transition period).
- Constituents affected by biological processes, i.e., chemical oxygen demand (COD), will reach a peak in concentration during the acclimatization of the microbial population, but will then decrease to levels that can presumably be maintained indefinitely.

Tables 1 and 2 illustrate various parameters that indicate water quality from the Dan Region pilot and full-scale plant operation. Stage I facilities can process 11.5 million gallons per day (mgd). Stage II, to be completed in the mid-1980s, will include a modified activated sludge process with nitrification and denitrification capabilities and, operating in parallel with Stage I facilities, will increase the total capacity to 20 mgd.

At present, the tertiary effluent is recharged into an aquifer containing potable water, which presents a possible pollution danger. The recharge and pumping operations are carefully managed to ensure that the bulk of the recharged water is pumped by the project recovery wells and does not spread to drinking water supply wells near the recharge area. Most of the recharged tertiary effluent is then used for agricultural irrigation. However, temporary reuse of small amounts (5 percent) of high quality reclaimed water mixed with large amounts of natural water is possible and has been agreed to in principle by Israeli health authorities, provided implementation of the dual supply system progresses satisfactorily /4/.

Table 1

DAN REGION
CONCENTRATIONS OF TOXIC ORGANIC COMPOUNDS IN
TERTIARY EFFLUENT COMPARED TO
DRINKING WATER STANDARDS

Pesticides	Concentration in Tertiary Effluent a/ (µg/L)	Recommended Limit for Public Water Supplies b/ (µg/L)	Maximum Contaminant Levels (MCLs) c/ (µg/L)
Lindane	<0.5	5	4
Endrin	<1	0.5	0.2
Toxaphene	<5	5	5
Methoxychlor	<5	1 000	100
2,4-D	<10	20	100
2,4,5-TP	<5	30	10
Polynuclear Aromatic Hydrocarbons (PAHs)			
Fluoranthene	0.045		
3,4-Benzfluoranthene	0.012		
11,12-Benzfluoranthene	0.035		
3,4-Benzpyrene	0.006		
1,12-Benzpyrene	0.001		
Indeno (1,2,3-cd) Pyrene	--		
Total PAHs	0.099		0.200 d/

a/ From Reference 4.
b/ According to 1972 EPA Water Quality Criteria. /8/
c/ According to U. S. National Interim Primary Drinking Water Regulations. /9/
d/ According to WHO International Standards for Drinking Water. /10/

Table 2

DAN REGION EFFLUENT QUALITY AT VARIOUS TREATMENT STEPS*

Pilot Plant

Parameter+	Secondary Effluent		High Lime Effluent		Tertiary Effluent	
	Summer	Winter	Summer	Winter	Summer	Winter
pH	8.3	8.2	11.5	11.5	10.6	10.0
Suspended Solids	130	225	30	77	10	13
BOD	45	57	8	12	3	3
COD	320	350	100	113	85	63
Ammonia	27	36	20	30	3	10
Total Nitrogen	39	51	26	36	6	13
Phosphorus	10.7	11.8	1.0	3.0	0.2	1.5
Dissolved Solids	870	770	690	650	630	660

Full-Scale Plant

Parameter+	Raw Sewage		Secondary Effluent		High Lime Effluent		Tertiary Effluent		Reclaimed Water
	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	
pH	7.9	7.9	8.3	8.3	11.7	12.1	10.1	10.2	8.0
Suspended Solids	230	249	212	247	55	154	8	20	0
BOD	230	226	60	53	13	19	7	6	0.2
COD	510	465	355	298	90	125	75	67	10
Ammonia	38	46	21	27	24	30	1	5.5	0.02
Total Nitrogen	58	70	53	55	31	39	6	10.5	5
Phosphorus	11.9	12.0	11.6	11	2.0	1.6	0.5	0.8	0.05
Dissolved Solids	875	778	860	739	830	737	640	588	630

* From Reference 6.
+ Except for pH, all concentrations are in mg/L.

Windhoek, Namibia

Because Namibia is a country with an economy stressed by water shortage, reuse has been recognized as an essential component of national water management. Since 1956, the government has promoted water reuse. One result of this policy is the reclamation plant at Windhoek, the only full-scale facility in the world where waste water effluent is reclaimed for direct potable use /11/.

The reclamation plant came about because of the urgent conditions at Windhoek. When the plant was commissioned in 1969, the city could no longer meet its water needs from conventional supplies. Two aspects of its system that uniquely facilitated direct reuse are:

- ° Industrial effluents could be easily segregated from domestic effluent.
- ° The site of the waste water treatment facility allowed the reclamation plant to be integrated easily, resulting in considerable savings.

Because no other city in either South Africa or Namibia has been subject to the extreme conditions found in Windhoek, no other reclamation projects for potable water have been established. However, a strong research effort is being maintained in South Africa to provide data on the health aspects of direct reuse.

In several areas in South Africa, the economically feasible water supply alternatives are being rapidly exhausted, and more reclamation plants for potable water can be expected during the latter part of the 1980s.

Treatment at the Windhoek plant consists of lime addition, coagulation, sedimentation, ammonia stripping, recarbonation, breakpoint chlorination, secondary sedimentation, filtration, activated carbon adsorption, and final chlorination. The treated water is then mixed with treated fresh water and delivered. The plant is operated intermittently, as needed, to supplement the domestic water supply. Up to 25 percent of the domestic supply may be reclaimed water /12/.

Ground Water Recharge Projects in the United States

Several projects in the United States will help determine the future of waste water recharge as a feasible water source here.

Nassau County, New York

Nassau and Suffolk counties in New York use a ground water aquifer underlying Long Island as their sole source of potable water. The effects of increased ground water pumpage and of a sewering program have resulted in a net decline in the water table and a landward movement of saline ground water from North Long Island Sound.

In 1963, Nassau County initiated research into water reclamation and ground water recharge, with emphasis on forming a hydraulic barrier to retard saltwater intrusion /13/. A 400 gallon per minute (gpm) water renovation plant and a 500-foot injection well were operated from 1968 to 1973. Based on data from this pilot facility, water reclamation was found to be feasible; deep well injection was not feasible, because recharge caused clogging of the aquifer around the injection well, making injection difficult /14/.

In 1971, a report by Greeley and Hansen recommended that Nassau County adopt a means of supplementing its ground water supply /15/. Alternatives included:

- Importing water from Suffolk County.
- Importing water from upstate New York.
- Water renovation and ground water recharge.

The report recommended the upland recharge of 92 mgd for the year 1990. In August 1973, the Environmental Protection Agency authorized work on plans and specifications under the Construction Grants Program. These were completed in 1976.

On June 28, 1976, Nassau County was awarded $27.6 million for a combined Step 2 (design) and Step 3 (construction) grant. This demonstration plant had to produce effluent that met the requirements shown in Tables 3 and 4. To meet these requirements, the following processes were used:

- Primary sedimentation.
- Carbon oxidation nitrification.
- Sedimentation followed by denitrification and aeration.
- Sedimentation followed by filtration.
- Carbon adsorption.
- Chlorination (chlorine).
- Storage, then transmission, using 6.2 miles of concrete pipe.

Table 3

NASSAU COUNTY
WATER QUALITY STANDARDS FOR CEDAR CREEK RECLAMATION-RECHARGE PROJECT*

Constituent	Desired Limit (mg/L)	Constituent	Desired Limit (mg/L)
ABS	0.5	Selenium	0.01
Aluminum	0.1	Silver	0.05
Arsenic	0.05	Sodium	50% of cations or 20 mg/L
Barium	1.0	Sulfate	250
BOD_5	2.0	TOC	3.0
Boron	1.0	Uranyl Ion	5.0
Cadmium	0.01	Zinc	0.3
Calcium	<Sat Conc.	Coliforms	Max. 4/100 mL
CCE	0.2	Aldrin	0.017
Chloride	250	Chlordane	0.003
Chlorine Res. (Free)	1.0	DDT	0.042
Chromium (hexavalent)	0.05	Dieldrin	0.017
Copper	0.2	Endrin	0.001
Cyanide	0.1	Heptachlor	0.018
Fluoride	1.5	Hep. Epoxide	0.018
Iron & Manganese Combined	<0.3	Herbicides	0.1
Lead	0.05	Methoxychlor	0.035
Mercury	0.005	Org. PO_4 and Carbamates	0.1
Total Nitrogen	3.0	Toxaphene	0.005
O_2 Consumed	2.0	Color	15 units
		TON	3 units
Phenols	0.001	TDS	500
		Turbidity	0.5 JTU
Phosphorus	0.1	SS	1.0
		pH	6.5 to 8.5 units

---

* From Reference 13.

Table 4

NASSAU COUNTY
ORGANIC COMPOUND RECHARGE REQUIREMENTS*

Effluent Parameter	Discharge Limitation Daily Maximum (µg/L)	Monitoring Requirements	
Organic		Measurement Frequency	Sample Type
Chloroform	100	Weekly	Grab
Trichloroethylene	10	Weekly	Grab
Tetrachloroethylene	50	Weekly	Grab
Ethylbenzene	50	Weekly	Grab
1,1 Dichloroethane	50	Weekly	Grab
1,1,1 Trichloroethane	50	Weekly	Grab
Carbon Tetrachloride	5	Weekly	Grab
Methylene Chloride	50	Weekly	Grab
Dichlorodifluoromethane	50	Weekly	Grab
Toluene	50	Weekly	Grab
Benzene	N.D.	Weekly	Grab
p-dichlorobenzene	4.7	Weekly	Grab
o-dichlorobenzene	4.7	Weekly	Grab

---

* From Reference 13.

- Recharge facilities totaling 60 acres.

The recharge facilities will include both injection wells and percolation ponds; 2 mgd will be recharged through the wells and 2 mgd recharged through the ponds.

The recharge site is surrounded by 46 observation wells for monitoring ground water quality changes. In addition, a composite sampler will be used to monitor the recharge site storage reservoir for dissolved oxygen (DO), turbidity, temperature, pH, residual chlorine, and specific conductance. Water from two of the ten basins will be analyzed for pH, DO, and sulfide.

Recharge was to begin in early 1980, with operation of all facilities for a minimum of three years and a maximum of five years. Assuming successful operations, additions can be made to the permanent filter and adsorption building to increase the total recharge volume to 20 mgd.

Flushing Meadows, Arizona

Flushing Meadows is located in the bed of the Salt River, west of Phoenix. In that area, about one-third of the 1 million acre-feet of water used annually by agriculture and municipalities is ground water /16/. Ground water levels in some parts of the valley have been declining at about 10 feet per year. With increasing urbanization of the valley, reclaimed waste water was looked at as a potential water resource.

The Flushing Meadows Project was a field demonstration of the feasibility of renovating secondary treated waste water by ground water recharge through infiltration basins. The project began in 1967 and operated for ten years /17/. The objective of the project was to determine whether rapid infiltration would achieve tertiary treatment of the effluent necessary for irrigated agriculture, recreational lakes, and certain industries.

The recharge facilities consisted of six infiltration basins in the loamy sand of the riverbed. Secondary effluent (activated sludge process) was pumped into the basins at one end and left the basins at the other end through overflow structures that controlled the water depth in the basins. The soil profile beneath the basins consisted of about 3 feet of fine, loamy sand, underlain by coarse sand and gravel layers to a depth of about 240 feet, where a clay layer begins. The static water table was at a depth of about 10 feet. The observation wells were 20 feet deep, except for one at 30 feet and one at 100 feet.

Findings and conclusions of the study have been documented and are summarized as follows: /17,18,19/

- Secondary effluent can be effectively renovated for unrestricted irrigation and primary contact recreation by ground water recharge through infiltration.

- The soil filtration process yielded essentially complete removal of suspended solids, biochemical oxygen demand (BOD), and fecal coliforms.

- Nitrite, ammonium, and organic nitrogen concentrations were reduced; measured nitrate concentrations, ranging up to 50 mg/L, increased.

- Phosphate removal was about 50 percent after 30 feet of underground travel.

- Boron was not removed by percolation.

- Copper and zinc concentrations were reduced up to 80 percent; lead and cadmium remained the same in effluent and filtrate.

- Total dissolved solids (TDS) increased slightly.

- No viruses were detected in any renovated water samples.

- There was no indication of gradual clogging of the soil profile of the aquifer or of a decrease in the renovation efficiency of the system. (More specific soil capacity removal characteristics are discussed in Chapter 5 of this report.)

- Table 5 presents the general range of quality achieved by the project.

Table 5

FLUSHING MEADOWS
GENERAL RANGE OF QUALITY PARAMETERS OF SECONDARY SEWAGE EFFLUENT AND RENOVATED WATER FROM EAST CENTER WELL*

Constituent	Effluent (mg/L)	East Center Well (mg/L)
BOD	10-20	0-1
COD	30-60	10-20
TOC	10-25	1-7
Org-N	2-6	0.3-0.7
NO_3-N	0-1	0.1-50
NO_2-N	0-3	0.1
NH_4-N	20-40	5-20
PO_4-P	7-12	4-8
F	3-5	2-2.5
B	0.7-0.9	0.7-0.9
Cu	0.1	0.02
Zn	0.2	0.1
Cd	0.008	0.007
Pb	0.08	0.07
Total Salts	1 000-1 200	1 000-1 200
pH	7.7-8.1	6.9-7.2
Fecal Coliforms per 100 mL	10^5-10^6	0-10^2

---

* From Reference 19.

Phoenix 23rd Avenue Project, Arizona

Ground water supplies for irrigation are replenished by recharging with secondary treated waste water from the city of Phoenix. The recharge system consists of four parallel 10-acre rapid infiltration basins having a total recharge capacity of 11 million gallons/day. Monitoring wells are located in the center and on the north and south sides of the facility.

Until the end of November 1980, secondary waste water was recharged. From September to November 1980, samples were taken from the monitoring wells and analyzed for organic constituents. Table 6 summarizes selected results of that monitoring /20/. At the end of November 1980, the project began using chlorinated secondary effluent for recharge. From April through June 1981, samples were taken from the monitoring wells and analyzed similarly to the samples taken in the earlier sampling period. Table 7 shows the most significant results /20/.

Tables 6 and 7 demonstrate that soils efficiently remove many organic compounds. However, the data also indicate some compounds are not removed and, in fact, may be concentrated in the soils. The similarities between Table 6 and Table 7 indicate chlorination of the recharge water has minimal effects.

Other Out-of-State Recharge Projects

Lake George, New York, has a secondary (trickling filter) treatment plant that uses natural delta sand deposits near the lake as an infiltration area for the unchlorinated treated effluent. The lake also supplies drinking water, which is treated with with chlorine.

In 1968, Rensselear Polytechnic Institute evaluated the ability of the Lake George Village sewage treatment plant to renovate waste water, with particular concern for nutrients that could ultimately reach the lake. Ground water is more than 56 feet below the surface. This study indicated that BOD, coliforms, ammonia, and organic nitrogen were almost completely removed, in the top 10 feet of the sandbeds /21/.

Table 6

PERCENTAGE CONCENTRATION DECREASE IN ORGANIC SUBSTANCES BY PERCOLATION OF UNCHLORINATED EFFLUENT THROUGH SOIL†

	Average Basin Concentration (27 samples)		Center Well 18 m deep Decrease (%) (6 samples)		Center Well 30 m deep Decrease (%) (6 samples)		North Well 23 m deep Decrease (%) (6 samples)		South Well 23 m deep Decrease (%) (6 samples)	
Constituent	Geometric Mean (µg/L)	Spread Factor	Average	Significance Level*	Average	Significance Level*	Average	Significance Level*	Average	Significance Level*
					Halogenated					
Chlorinated Aliphatic Hydrocarbons										
chloroform	2.72	1.63	61	0.001	68	0.001	74	0.001	71	0.001
1,1,1-trichloroethane	2.94	3.27	34	0.15	49	0.01	31	0.10	61	0.001
carbon tetrachloride	0.12	2.41	0	1.0	0	1.0	-25	0.50	33	0.01
trichloroethylene	0.91	2.04	-180	0.001	-160	0.001	-68	0.001	-9	0.5
tetrachloroethylene	2.63	2.03	-97	0.001	-29	0.2	-57	0.001	9	0.6
Chlorinated Aromatics										
o-dichlorobenzene	3.52	1.88	25	0.20	34	0.02	40	0.001	53	0.001
m-dichlorobenzene	0.79	2.25	58	0.002	58	0.001	63	0.001	71	0.001
p-dichlorobenzene	2.25	1.60	33	0.002	33	0.002	44	0.001	48	0.001
1,2,4-trichlorobenzene	0.19	1.97	42	0.10	37	0.20	37	0.10	32	0.10
trichlorophenol	0.01	ID	0	ID	0	ID	0	ID	0	ID
pentachlorophenol	0.02	ID	0	ID	0	ID	0	ID	0	ID
pentachloroanisole	0.43	ID	-150	ID	-160	ID	14	ID	0	ID
					Hydrocarbons					
Aliphatic Hydrocarbons										
5-(2-methylpropyl) nonane	0.35	1.84	94	?	89	0.05	94	0.001	94	0.005
2,2,5-trimethylhexane	0.11	2.49	82	?	82	?	82	?	82	?
6-methyl-5-nonene-4-one	0.41	3.21	93	0.001	90	0.001	95	0.001	93	0.001
2,2,3-trimethylnonane	0.21	2.10	76	0.01	76	0.01	76	0.01	76	0.01
2,3,7-trimethyloctane	0.12	1.90	50	0.05	75	0.01	75	0.01	83	?
Aromatic Hydrocarbons										
o-xylene	0.45	3.19	67	0.02	69	0.001	69	0.001	73	0.001
m-xylene	0.76	2.43	78	0.001	82	0.001	75	0.001	76	0.001
p-xylene	0.17	2.45	53	0.05	71	0.01	53	0.05	59	0.01
C_3-benzene isomer	0.56	2.91	84	0.001	86	0.001	82	0.001	80	0.001
C_3-benzene isomer	0.48	3.04	85	0.001	88	0.001	90	0.001	90	0.001
styrene	0.26	3.84	92	?	92	?	92	?	92	?
1,2,4-trimethyl benzene	0.80	4.59	78	0.002	84	0.001	84	0.001	83	0.001
ethylbenzene	0.19	2.38	53	0.005	58	0.05	47	0.10	37	0.20
naphthalene	0.22	2.84	68	0.05	82	0.10	86	0.01	91	?
phenanthrene	0.10	ID	80	ID	80	ID	80	ID	80	ID
diethylphthalate	19	ID	20	ID	75	ID	80	ID	95	ID

---

†From Reference 20.

*Values with "?" indicate that groundwater concentrations were below the detection limit of 0.02 µg/L. Values of 0.05 or less are significant.

ID = Insufficient data for statistical evaluation.

Chlorides were not removed and nitrates were increased, apparently due to oxidation of ammonia and organic nitrogen. Phosphorus removal appeared to be a function of past sandbed use. A 1974 study found complete removal of coliforms, BOD, ammonia, organic nitrogen and phosphate within 2,000 feet horizontal travel of the infiltered water. As in the previous study, chloride concentrations were not changed, and nitrates increased. /22/

In Texas, long-term effluent reuse has been practiced /23/. The 80 reuse projects in the High Plains area include application of reclaimed water for ranch irrigation near Lubbock, for agricultural irrigation on the Texas Tech University campus, and for maintaining recreational lakes and for golf course irrigation at Reese Air Force Base.

Also in Texas, the city of El Paso has studied means of supplementing the existing water supply and has chosen recharge by direct injection of reclaimed waste water /24/. Pilot work indicated the proposed process could

Table 7

PERCENTAGE CONCENTRATION DECREASE IN ORGANIC SUBSTANCES BY PERCOLATION OF CHLORINATED EFFLUENT THROUGH SOIL†

	Average Basin Concentration (36 samples)		Center Well 18 m deep Decrease (%) (6 samples)		Center Well 30 m deep Decrease (%) (6 samples)		North Well 23 m deep Decrease (%) (6 samples)		South Well 23 m deep Decrease (%) (6 samples)	
Constituent	Geometric Mean (µg/L)	Spread Factor	Average	Significance Level*	Average	Significance Level*	Average	Significance Level*	Average	Significance Level*
Halogenated Aliphatic Hydrocarbons										
chloroform	3.46	1.52	88	0.0001	86	0.0001	87	0.0001	80	0.0001
1,1,1-trichloroethane	1.41	2.45	84	0.0001	85	0.0001	76	0.0001	63	0.0002
carbon tetrachloride	0.12	2.15	42	0.1	58	?	58	?	58	?
bromodichloromethane	0.26	1.91	62	?	62	?	62	?	62	?
trichloroehtylene	0.39	2.22	-267	0.0001	-323	0.0001	-154	0.0001	-597	0.0001
dibromochloromethane	0.23	1.94	57	?	57	?	57	?	57	?
tetrachloroethylene	1.69	2.40	31	0.1	1	0.8	4	0.7	-94	0.005
bromoform	0.08	3.35	10	?	10	?	10	?	10	?
Chlorinated Aromatics										
o-dichlorobenzene	2.40	2.11	10	0.6	21	0.2	-1	0.95	-15	0.5
m-dichlorobenzene	0.38	2.66	5	0.7	29	0.2	0	1.0	-5	0.7
p-dichlorobenzene	1.82	1.86	10	0.5	24	0.1	11	0.5	3	0.7
1,2,4-trichlorobenzene	0.38	1.90	71	0.0001	68	0.0001	61	0.0001	66	0.0001
trichlorophenol	0.02	ID	0	ID	0	ID	0	ID	0	ID
pentachlorophenol	0.04	ID	0	ID	0	ID	0	ID	0	ID
pentachloroanisole	0.18	ID	-120	ID	-83	ID	-18	ID	-213	ID
Aliphatic Hydrocarbons										
5-(2-methylpropyl) nonane	0.57	1.86	96	?	96	?	96	?	96	?
2,2,5-trimethylhexane	0.18	2.74	89	?	89	?	89	?	89	?
6-methyl-5-nonene-4-one	0.94	2.49	98	0.0001	99	0.0001	99	0.0001	99	0.0001
2,2,3-trimethylnonane	0.25	2.31	92	?	92	?	92	?	92	?
2,3,7-trimethyloctane	0.27	2.30	93	?	93	?	93	?	93	?
Aromatic Hydrocarbons										
o-xylene	0.50	2.71	88	0.0001	92	0.0001	86	0.0001	86	0.0001
m-xylene	1.00	2.14	98	0.0001	98	0.0001	98	0.0001	97	0.0001
p-xylene	0.12	3.86	92	0.0001	92	?	92	?	92	0.0005
C_3-benzene isomer	0.34	4.46	94	?	94	?	94	?	94	?
C_3-benzene isomer	0.53	2.71	96	0.0001	96	0.0001	96	0.0001	96	?
styrene	0.58	2.39	98	0.0001	98	0.0001	97	0.0001	98	0.01
1,2,4-trimethyl benzene	1.04	3.81	96	0.0001	96	0.0001	98	?	97	0.0001
ethylbenzene	0.15	3.99	67	0.2	93	0.002	80	0.005	87	0.0001
naphthalene	0.63	2.55	91	0.0001	87	0.0001	94	0.0001	83	0.0001
phenanthrene	0.10	ID	90	ID	90	ID	90	ID	90	ID
diethylphthalate	10	ID	90	ID	90	ID	90	ID	90	ID

---

†From Reference 20.

*Values with "?" indicate that groundwater concentrations were below the detection limit of 0.02 µg/L. Values of 0.05 or less are significant.

ID = Insufficient data for statistical evaluation.

meet drinking water standards (see Table 8). Direct injection was selected due to its low surface area requirements, as compared to the greater land requirements for recharging by surface percolation. This project has not yet been fully implemented.

Ground Water Recharge Projects in California

In 1972, 31 million acre-feet of water was used in California. This exceeded the reliable water supply by 2.4 million acre-feet, mainly at the expense of ground water reserves. By the year 2000, there will be a shortage in the range of 3 to 6 million acre-feet of water annually, depending on population growth, new dam construction, and available storage facilities /25/. Also, in 1985 California's water supply from the Colorado River will be significantly reduced. Planning and implementing programs to correct ground water overdrafts and to meet water needs for the year 2000 must begin now. Many major and minor water reclamation projects are operating in California,

Table 8

OVERALL PILOT PLANT TESTING RESULTS AT EL PASO, TEXAS†

Constituent	Unit	Raw Influent	PACT* Influent	PACT Stage 1 Effluent	PACT Stage 2 Effluent	High Lime	Regen. Carbon Stage 1	Regen. Carbon Stage 2	0.4 mm Filter	0.4 Residual Ozone	GAC** Filter	Proposed Effluent
COD	mg/L		260		5.6	10.4		<8.7	13.0	<8.7	<8.7	<10
TOC	mg/L		35	5.0	2.2	2.2		1.81	1.81	1.81	0.78	<2.0
NH_3	mg/L		23	<0.1	<0.1							<0.5
NO_3(TKN)	mg/L		(37)		0.3(1.5)							1.5(2.0)
Coliforms - Total MPN	100 mL				38 000	1		15	2	0	0	0
Alkalinity-T (Alkalinity-P)	mg/L	235	235		140	172(124)		172(0)	158(0)	150(0)		150
Total Phosphorus	mg/L as P				7.01	1.0					<1.0	0.1
pH					7.36	11.1	9.3	7.45	7.8	7.8	7.8	7.5
Turbidity	NTU	97			2.6	9.4		2.5	0.35	0.20	0.16	0.5
TDS	mg/L	769			622			667	645	633	649	680
TH	mg/L as $CaCO_3$	120			124			144	140	142		140
Ca	mg/L	35			38			51	50	52		50
Cl	mg/L	122			122			124	124	124	140	140
Mg	mg/L	7.9			7.0			4.0	3.6	2.9		3.0
Na	mg/L	192			152	145		153	149	145		145
SO_4	mg/L	125						125	125	125		125
Cyanide	mg/L										<0.015	0.02
As	mg/L		0.006	0.006	0.0015	0.0015					.005	<0.05
Ba	mg/L		0.15	0.28	0.13	0.14					0.02	0.1
Cd	mg/L		<0.01	<0.01	<0.01	<0.01					<0.003	<0.01
Cr	mg/L		<0.03	<0.03	0.04	0.03					0.012	<0.01.
Cu	mg/L		0.004	0.08	0.022	0.012					0.010	<0.05
Fe	mg/L				0.036	0.029					0.018	0.05
Pb	mg/L		0.032		0.028	0.026					0.026	<0.05
Mn	mg/L		0.026		0.010	0.010					0.010	<0.05
Hg	mg/L		<0.001	<0.001	<0.001	<0.001					<0.001	0.0014
Sc	mg/L		.0035		0.0031							<0.01
Ag	mg/L		<0.01	<0.01	<0.01	<0.01					<0.01	<0.01
Zn	mg/L		0.058		0.012	<0.010					0.003	<0.1
Color	APHA units	52									<5	<10
Σ THM	μg/L		1.2		<0.05							<100
Σ THMFP	μg/L 24 hr	100-1 000			20-300							<100

† From Reference 24.
* A suspended growth biological system with powdered activated carbon.
** Granulated activated carbon.

including both direct injection and surface spreading recharge projects.

Two significant reclamation projects employ ground water recharge by direct injection; both were initiated primarily to create a barrier to seawater intrusion.

Orange County Water District, Water Factory 21

Water Factory 21 is located in the city of Fountain Valley, about 5 miles from the ocean. The purpose of Water Factory 21 is to inject reclaimed water into the seaward portion of a potable water aquifer to create a barrier against seawater intrusion. Effluents from an advanced waste treatment (AWT) process and a reverse osmosis (RO) unit are blended with deep well water and pumped into the aquifer via a series of 23 multicasing injection wells /26,27/. Seven extraction wells, located 2 miles seaward from the injection line, extract intruding sea water before it reaches the barrier and return the extracted water to the ocean. This combination of extraction and injection creates an underground hydraulic pressure mound that prevents intrusion (see Figures 2, 3, and 4).

The injection water is a blend of AWT water with RO effluent and deep well water. Well water comprises 35 to 50 percent of the total injection water. Once underground, 10 percent of the

Figure 2

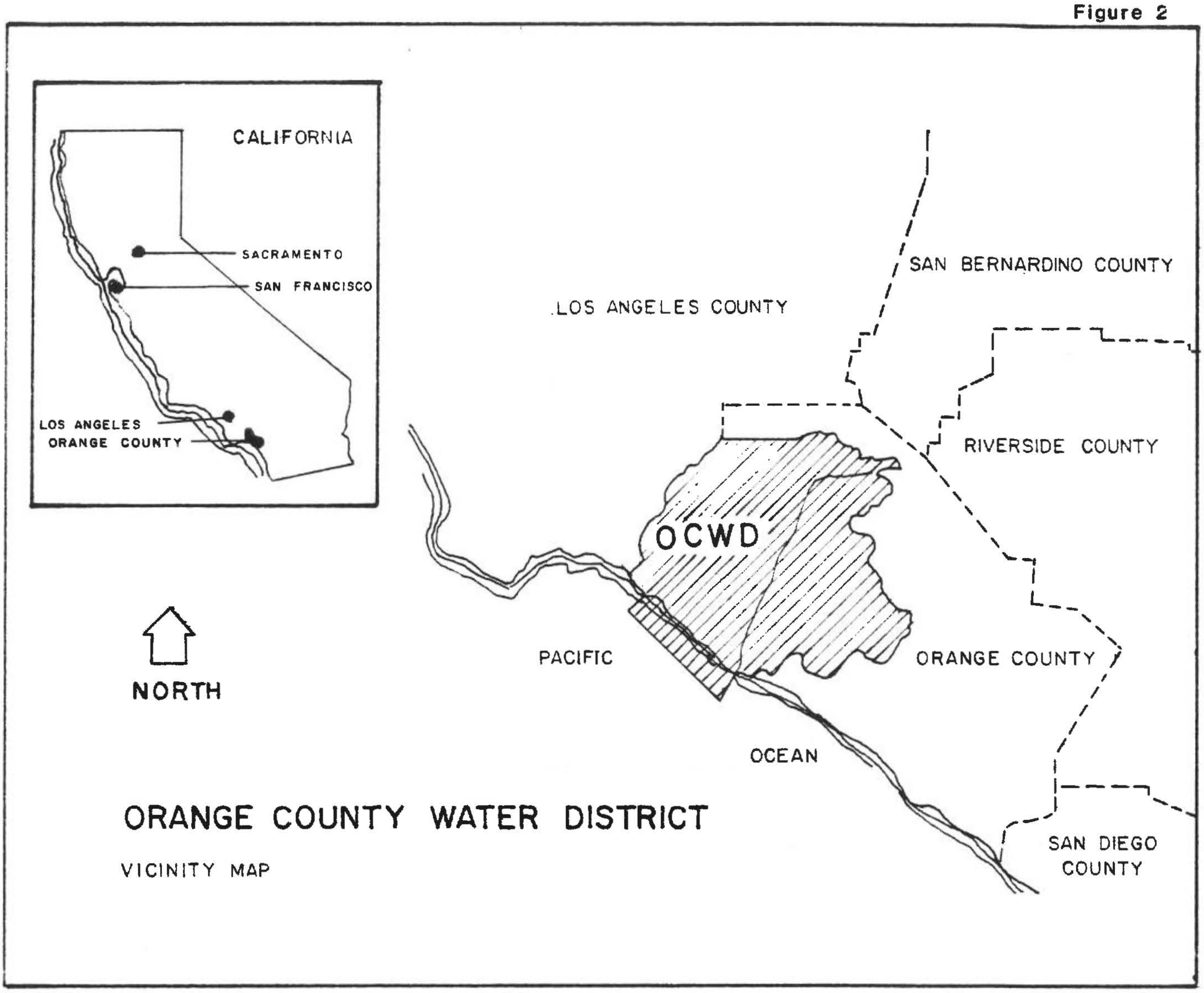
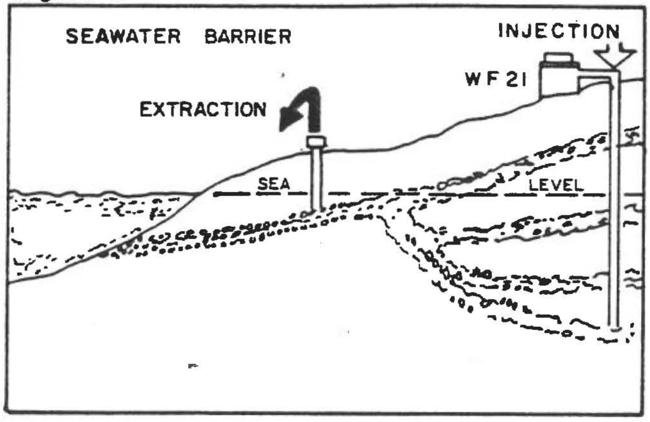


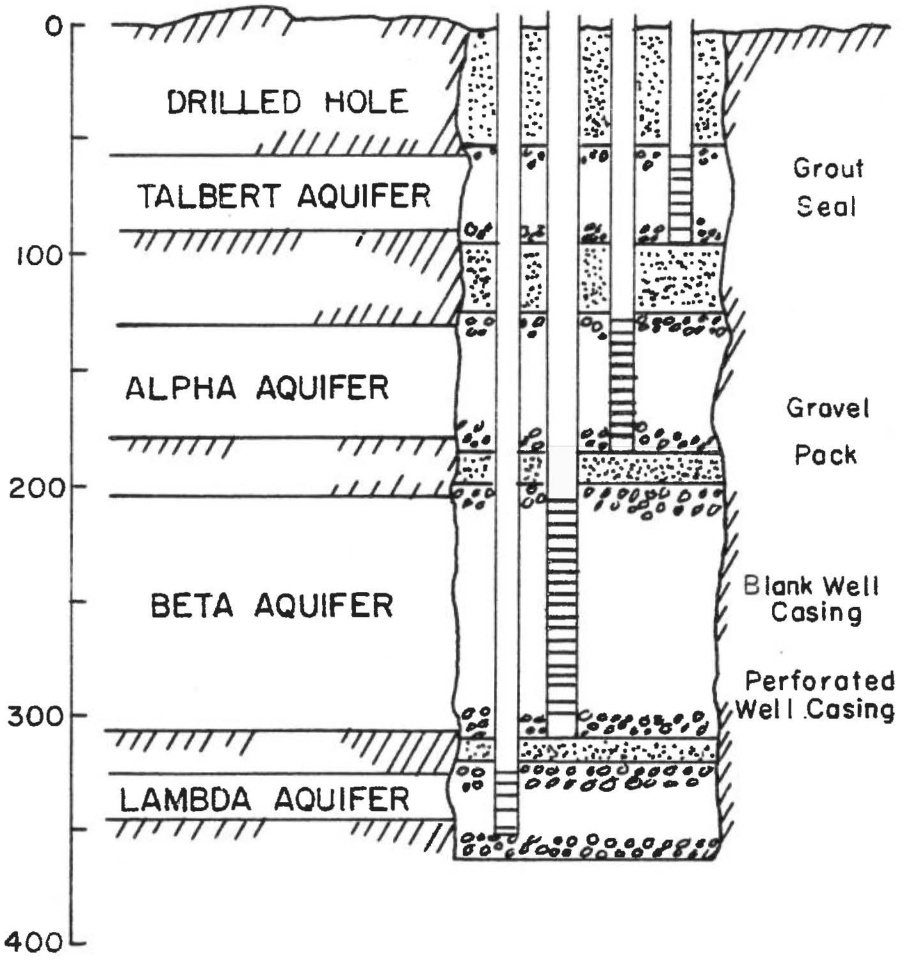
Figure 3



injected water flows to the ocean; the remaining 90 percent flows into the ground water basin, augmenting Orange County's supplies /28/.

The principal facility of Water Factory 21 is a 15 mgd advanced waste water reclamation plant, incorporating a 5 mgd reverse osmosis plant. Treatment includes: chemical clarification, ammonia stripping, recarbonation, multimedia filtration, carbon adsorption, and chlorination prior to reverse osmosis treatment (see Figure 5).

Figure 4



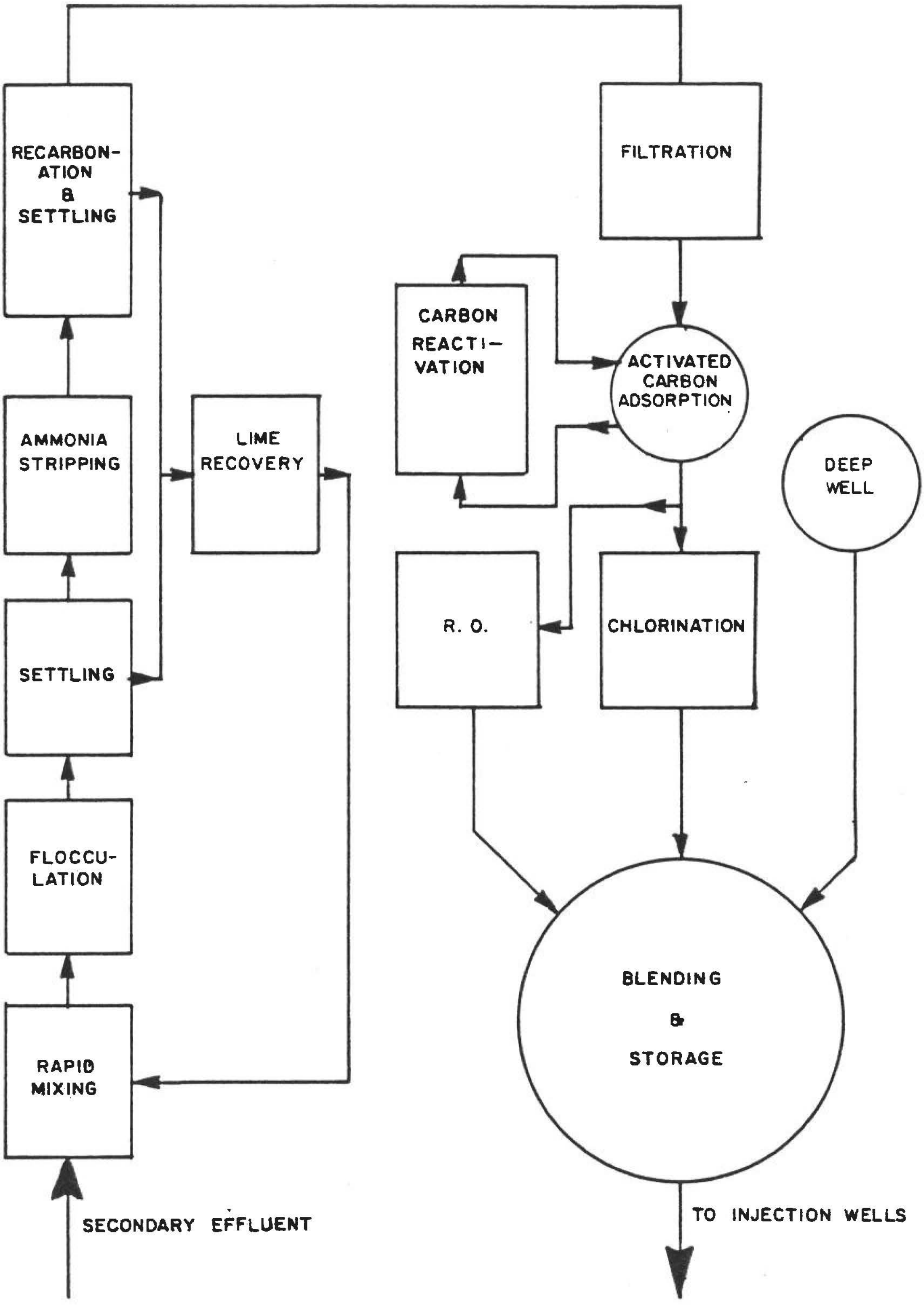
TYPICAL INJECTION OR OBSERVATION WELL

A network of 170 water supply wells aids in monitoring any changes in the ground water quality due to the injection program /26/. The TDS of the recharge water is about 300 mg/L, based upon an electrical conductivity of 500 uS/cm /29/. The recharge water will, therefore, be substantially better in mineral quality than the water supplies from the Colorado and Santa Ana Rivers (TDS 700 to 800 mg/L) /26/. Table 9 characterizes inorganic constituents and coliform concentrations in Water Factory 21 injection water. Constituents are compared to State standards for injection water. Sodium and phenol were the only constituents exceeding the standards more than 10 percent of the time.

Table 10 compares influent and effluent quality of Water Factory 21 water to Federal Interim Primary Drinking Water Standards. Except for coliforms in the RO effluent, treatment satisfactorily removed contaminants found in the influent (coliforms could be easily controlled).

Table 11 compares Water Factory 21 effluent quality to Federal Water Quality Criteria for toxic pollutants (Priority Pollutants) and Federal and State drinking water criteria. Only beryllium and nickel concentrations exceeded the Priority Pollutant criteria. A further discussion of these criteria is presented in Chapter 7.

Figure 5



WASTEWATER RECLAMATION PROCESS FLOW DIAGRAM

Table 9

COMPARISON BETWEEN STATE AND REGIONAL SPECIFIED MAXIMUM CONTAMINANT LEVEL FOR INJECTION WATER AND ACTUAL MEASURED CONCENTRATIONS DURING PERIOD MARCH 1978 THROUGH MARCH 1981†

Contaminant+	State Specified MCL	Geometric Mean Concentration	Predicted Percent Time MCL Exceeded*	Measured Percent Time MCL Exceeded** (No. of Samples Analyzed)
EC	900 S/cm	504 S/cm	11	1 (875)
Sodium	110	72	16	12 (155)
Hardness ($CaCO_3$)	220	54	4	0 (154)
Sulfate	125	42	12	4 (257)
Chloride	120	62	8	5 (261)
Ammonium	4	0.27	6	3 (513)
Total Nitrogen	10	2.8		8 (148)
Fluoride	0.8	0.46	7	2 (153)
Boron	0.5	0.4	20	2 (155)
Chromium	0.05	0.002	5	4 (118)
Cadmium	0.01	0.0007	6	3 (140)
Selenium	0.01	<0.005	--	0 (127)
Copper	1.0	0.009	0.01	0 (117)
Lead	0.05	0.0009	0.2	0 (118)
Mercury	0.005	0.0005	3	0 (107)
Arsenic	0.05	0.004	<0.01	0 (105)
Iron	0.3	0.02	0.01	1 (138)
Manganese	0.05	0.002	0.01	1 (139)
Barium	1.0	0.005	<0.01	0 (117)
Silver	0.05	0.00045	0.01	0 (118)
COD++	30	11	1	0.2 (459)
MBAS	0.5	0.02	0.8	0 (147)
Cyanide	0.2	0.004	0.1	0 (143)
Phenol	0.001	0.0013	62	60 (103)
Coliforms	2.2/100 mL	0.01/100 mL	5	3 (509)
Turbidity++	1.0 TU	0.11 TU	<0.01	1 (408)

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†From Reference 30.

+Concentrations in mg/L unless otherwise noted.

*Based on lognormal model distribution.

**Given as 100 m/n where m = number of times MCL was exceeded out of n samples analyzed.

Table 10

COMPARISON OF RECLAIMED WATER QUALITY WITH EPA INTERIM PRIMARY DRINKING WATER MAXIMUM CONTAMINANT LEVELS JANUARY 1980 TO APRIL 1981*

		Influent		Chlorinated Effluent		Reverse Osmosis Effluent	
Contaminant[a]	MCL	Geometric Mean	Percent Time Exceed MCL	Geometric Mean	Percent Time Exceed MCL	Geometric Mean	Percent Time Exceed MCL
Trace Elements							
Arsenic	0.05	<0.005	<2	<0.005	<2	0.005	<2
Barium	1.0	0.094	<0.01	0.043	<0.01	0.001	<0.01
Cadmium	0.010	0.009	47	0.001	0.5	0.0001	<0.01
Chromium	0.05	0.033	20	0.006	2	0.0008	0.4
Fluoride	1.6	1.4	28	0.73	0.4		<0.01
Lead	0.05	0.005	0.1	0.004	4	0.0006	<0.01
Mercury	0.002	0.0003	5	0.0006	5	0.0003	3
Nitrate (N)	10	0.07	<0.01	1.3	0.01	0.25	<0.01
Selenium	0.01	<0.005	2	<0.005	2	<0.005	<2
Silver	0.05	0.0016	<0.01	0.0005	0.02	0.0002	<0.01
Pesticides[b]							
Endrin	0.0002	<0.00005	<1	<0.00005	<2	<0.00005	<3
Lindane	0.004	0.00011	<0.01	<0.00005	<2	<0.00005	<3
Methoxychlor	0.1	<0.0001	<1	<0.0001	<2	<0.0001	<3
Toxaphene	0.005	<0.0003	<1	<0.0001	<2	<0.0001	<3
2,4-D	0.1	<0.0001	<1	<0.0001	<2	<0.0001	<3
2,4,5-TP Silvex	0.01	<0.0001	<1	<0.0001	<2	<0.0001	<3
Radioactivity							
Radium 226 + 228	5 pCi/L	NA		NA		NA	
Gross Alpha	15 pCi/L	0.87 pCi/L	0.1	0.42 pCi/L	<0.01	0.48 pCi/L	1
Average Beta	4 mr/yr						
Other							
TTHM[c]	0.1	0.006	<0.01	0.011	0.4	0.003	<0.01
Turbidity	1 TU	NA		NA		NA	
Coliforms	1/100 mL	7×10^5/ 100 mL	100	0.17/100 mL	1	2.5/100 mL	80

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*From Reference 30.

[a] MCL and Geometric Mean in mg/L unless otherwise shown. NA = not analyzed.

[b] Lindane was only pesticide detected in any sample, percent less than values for all but Lindane based upon number of samples analyzed.

[c] Annual average from the distribution system.

Table 11

COMPARISON BETWEEN PRIORITY POLLUTANT HEALTH CRITERIA, DRINKING WATER STANDARDS, AND WATER FACTORY 21 AVERAGE EFFLUENT QUALITY†

	Health Criteria		EPA Drinking Water	Geometric Mean Concentration of Water Factory 21		
Pollutant*	Limit	10^6 Lifetime Cancer Risk	MCL or State MCL	Detection Limit	Chlorinated Effluent	Reverse Osmosis Effluent
Acenaphthene	20 µg/L			100	ND	ND
Acrolein	320 µg/L			NM	NM	NM
Acrylonitrile	0	58		NM	NM	NM
Aldrin/	0	74 pg/L		50	ND[b]	ND[b]
Dieldrin	0	71 pg/L		50	ND[b]	ND[b]
Antimony	146 µg/L			NM	NM	NM
Arsenic	0	2.2	50 µg/L	5 µg/L	ND	ND
Asbestos	0	30,000 Fibers/L		NM	NM	NM
Benzene	0	660		NM	NM	NM
Benzidine	0	120 pg/L		NM	NM	NM
Beryllium	0	6.8		1 µg/L	410	ND[b]
Cadmium	10 µg/L		10 µg/L	100	1.2 µg/L	70
Carbon tetrachloride	0	400		50	210	60
Chlordane	0	460 pg/L		50	ND[b]	ND[b]
Chlorinated benzenes						
Hexachlorobenzene	0	720		10	ND	ND
1,2,4,5-tetrachlorobenzene	48 µg/L			10	ND	ND
Pentachlorobenzene	74 µg/L			10	ND	ND
Trichlorobenzene	a	a		10	70	70
Monochlorobenzene	488 µg/L			10	70	70
Chlorinated ethanes						
1,2-Dichloroethane	0	940		50	ND	ND
1,1,1-trichloroethane	18.4 mg/L			50	180	50
1,1,2-trichloroethane		600		50	ND	ND
1,1,2,2-tetrachloroethane		170		50	ND	ND
Hexachloroethane		1.9 µg/L		50	ND	ND
1,1-Dichloroethane	a	a		50	ND	ND
1,1,1,2-tetrachloroethane	a	a		50	ND	ND
Pentachloroethane	a	a		50	ND	ND
Chloroalkyl ethers	0	3.8 pg/L		100	ND[b]	ND[b]
Chlorinated napthalene	a	a		100	ND	ND
Chlorinated phenols						
2,4,6-trichlorophenol[d]	0	1.2 µg/L		50	ND	ND
Chloroform	0	190	100 µg/L	50	10 µg/L	1.8 µg/L
2-chlorophenol	100			50	ND	ND
Chromium						
Cr (III)	170 mg/L					
Cr (VI)	50 µg/L		1 mg/L	100	6.5 µg/L	820
Copper	1 mg/L		1 mg/L	100	154 µg/L	3.9 µg/L
Cyanides	200 µg/L			100	9 µg/L	2 µg/L
DDT	0	24 pg/L		50	ND[b]	ND[b]
Dichlorobenzene	400 µg/L			10	100	60
Dichlorobenzidine	0	10		NM	NM	NM
Dichloroethylenes[e]	0	33		20	ND	ND
2,4-Dichlorophenols	3.1 mg/L			50	ND	ND
Dichloropropanes/propenes	87 µg/L			50	ND	ND
2,4-Dimethylphenol	2.1 mg/L			50	ND	ND

Table 11 (Continued)

	Health Criteria		EPA Drinking Water	Geometric Mean Concentration of Water Factory 21		
Pollutant*	Limit	10^6 Lifetime Cancer Risk	MCL or State MCL	Detection Limit	Chlorinated Effluent	Reverse Osmosis Effluent
Dinitrotoluene	0	110		100	ND$_b$	ND
Diphenylhydrazine	0	42		100	ND^b	ND^b
Endosolfan	74 µg/L			NM	NM	NM
Endrin	1 µg/L		200	50	ND	ND
Ethylbenzene	1.4 mg/L			10	20	40
Fluoranthene	42 µg/L			20	ND	ND
Haloethers	a	a		100	ND	ND
Halomethanes	0	190	100 µg/L	50	8 µg/L	1.7 µg/L
Heptachlor	0	280 pg/L		50	ND^b	ND^b
Hexachlorobutadiene	0	450		100	ND	ND
Hexachlorocyclohexane^f	0	9.2		50	ND^b	ND^b
Hexachlorocyclopentadiene	1.0 µg/L			100	ND	ND
Isophorone	5.2 mg/L			100	ND	ND
Lead	50 µg/L		50 µg/L	100	4 µg/L	650
Mercury	144		2 µg/L	500	570	280
Naphthalene	a	a		20	30	60
Nickel	13.4 µg/L			1 µg/L	19 µg/L	1.5
Nitrobenzene	19.8 mg/L			100	ND	ND
Nitrophenols	13.4 µg/L			50	ND	ND
Nitrosamines^g	0	0.8		NM	NM	NM
Pentachlorophenol	30.0 µg/L			50	50	50
Phenol	300 µg/L			50	ND	50
Phthalate esters^h	15 mg/L			100	1.7 µg/L	1.7 µg/L
Polychlorinated biphenyls (PCBs)	0	790 pg/L		50	50^b	ND^b
Polynuclear aromatic hydrocarbons	0	2.8		20	ND^b	ND^b
Selenium	10 µg/L		10 µg/L	5 µg/L	5 g/L	ND
Silver	50 µg/L		50 µg/L	100	480	150
Tetrachloroethylene	0	800		50	710	80
Thallium	13 µg/L			NM	NM	NM
Toluene	14 mg/L			10	390	130
Toxaphene	0	710 pg/L	5 µg/L	50	ND	ND
Trichloroethylene	0	2.7 µg/L		50	60	10
Vinyl chloride	0	2.0 µg/L		NM	NM	NM
Zinc	5 mg/L		5 mg/L	100 µg/L	53 µg/L	<100 µg/L
2,3,7,8-tetrachloro-dibenzo-p-dioxin	0	210x10^{-9}		50	ND^b	ND^b

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[†] From Reference 30.

*Concentrations are in ng/L, unless otherwise noted.

a = Sufficient information is not available.

d = Other chlorinated phenols have higher limits or else sufficient data is not available.

e = Limit for 1,1-dichloroethylene, other dichloroethylenes have higher limits or else sufficient data is not available.

f = Limit for lindane, value is higher for other hexachlorocyclohexanes, but none detected in sample.

g = Limit for n-nitrosodiethylamine, other nitrosamines have higher limits.

h = Limit for bis(2-ethylhexyl)phthalate, other pthalates have higher limits.

ND = Not detected in samples.

ND^b= Detection limit is above criteria level.

NM = Not measured.

= Concentration exceeds either the health criteria or the MCL or State MCL, whichever governs.

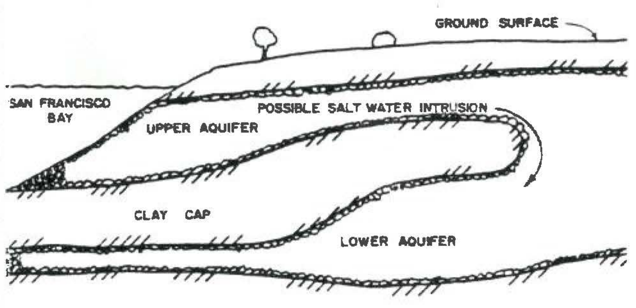
For protection of public health, the California Department of Health Services has imposed a number of restrictive provisions and requirements on the program. One of these is a requirement to provide an alternative source of domestic water supply to any user whose ground water is found to be impaired by the injection program /31/.

The Water Factory 21 experience is discussed more fully in Chapter 4.

Santa Clara Valley Water District, Palo Alto

About half of Santa Clara County water supplies come from ground water basins that have, in the past, been overdrafted /26/. Because of overdrafting, seawater intrusion has become extensive in the shallow aquifer in the Palo Alto area, and this water is no longer potable. The deeper, freshwater aquifer is potentially endangered as a result of inward movement of salt water spilling over the clay cap separating the shallow and deep aquifers (see Figure 6).

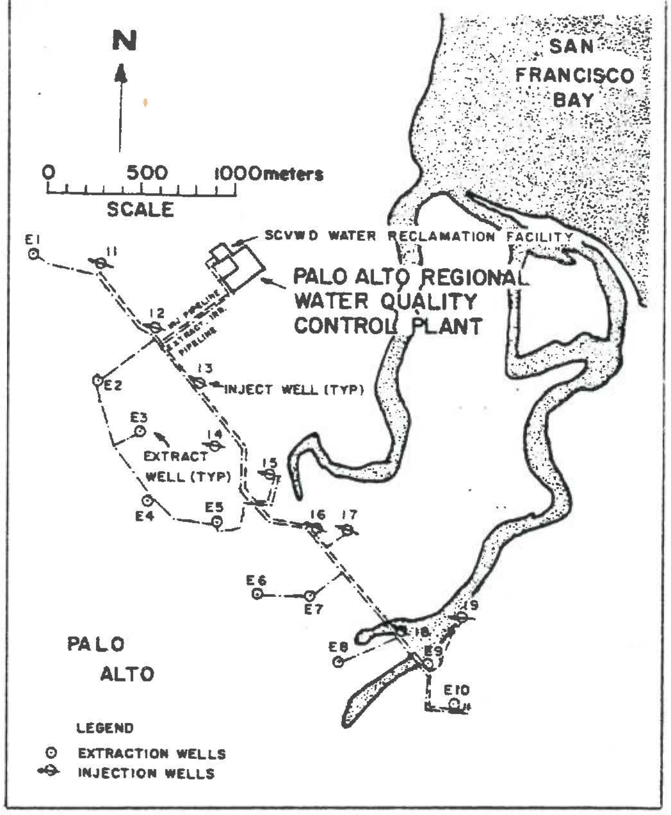
Figure 6



POSSIBLE CONTAMINATION OF LOWER AQUIFER BY SALT WATER INTRUSION

To combat the seawater encroachment, the water district, in cooperation with the California Department of Health Services and the Santa Clara County Health Department, designed and developed a 4 mgd advanced water treatment plant to provide reclaimed water for recharge to preserve and restore the ground water resource in the Palo Alto and Mountain View bayfront area (see Figure 7). The project was in full operation from 1976 to 1981. Limited operation continues to the present.

Figure 7



The goal of the project was to inject 2 mgd of AWT effluent into shallow aquifers and then extract the recharged water for irrigation use without allowing it to move inland and commingle with water used for potable supply /32/. The initial effect of injection was to develop a pressure mound to prevent further seawater intrusion and to flush the degraded ground water out of the shallow aquifer and replace it with better mineral quality effluent. It had been planned to renovate the shallow aquifer with treated effluent and then use the water for unrestricted irrigation. These plans could not be fully implemented. The complex makeup of the aquifer precluded success of the simple injection-extraction concept underlying the project.

The treatment facility won an award for excellence in engineering design /33/. It used previously abandoned, pile-supported waste water treatment plant structures built in 1934 and 1948. The treatment processes employed were:

- ° Ammonia stripping and breakpoint chlorination for nitrogen reduction.
- ° Ozonation ahead of carbon adsorption for combined disinfection.
- ° Preconditioning for enhanced organics removal.
- ° Filtration before and after carbon adsorption.
- ° A real-time computer-controlled monitoring system developed by the National Aeronautics and Space Administration.

Researchers at Stanford University evaluated changes in the quality of extracted ground water over time to quantify differences as a result of underground travel /34,35/. One finding was that the aquifer adsorbed some of the organic compounds, as evidenced by retardation of their transport through the aquifer. The retardation of movement indicated that strongly sorbing pollutants will be delayed many years before reaching the point of water extraction. This phenomenon allows more time for biodegradation to occur. However, less strongly sorbing pollutants can migrate through the soil and appear in extracted water. The findings of the Palo Alto project are discussed in more detail in Chapter 5.

Sanitation Districts of Orange and Los Angeles Counties, Montebello Forebay

Ground water recharge by surface spreading and percolation is practiced at several sites in California. Migration of effluent through the soil substantially reduces suspended solids, BOD, COD, pathogens, and most trace metals /32/. The surface spreading grounds operating in the Montebello, San Gabriel, and Rio Hondo areas of Los Angeles County are collectively referred to as the Montebello Forebay area.

The Montebello Forebay area of Los Angeles is undergoing an extensive investigation to evaluate the health aspects of water reuse by ground water recharge. This 3-1/2-year study is being conducted as part of the Orange and Los Angeles Counties Water Reuse Study. The Montebello Forebay area was chosen for the health effects study because ground water in the area has been replenished in part with reclaimed water since 1962. The studies include chemical and bacterial water quality characterizations, toxicological assessments, development of population exposure data, and an epidemiological study /36/.

The Sanitation Districts of Los Angeles County provides regional sewer services for almost 4 million people in 72 cities within the south coastal hydrologic region. The districts operate 10 treatment plants with a combined flow of 445 mgd, of which 25 mgd is reused /36/.

Effluent from three of the sanitation districts' treatment plants is being used to recharge the ground water of the Montebello Forebay area. The three plants are the Whittier Narrows plant, the San Jose Creek plant, and the Pomona Water Renovation plant. All three employ activated sludge secondary treatment; in addition, concerns about virus have caused dual-media filtration to be added to the Whittier Narrows and San Jose Creek facilities. The secondary effluent is disinfected by chlorination and discharged to flood control channels that convey the water to spreading grounds, where it percolates into ground water aquifers used for domestic supplies.

At present, 25 mgd of reclaimed water is percolated into Montebello Forebay. The spreading grounds, located along the Rio Hondo and San Gabriel rivers, have total percolation areas of 455 and 235 acres, respectively. The spreading grounds are subdivided into numerous individual basins, ranging from 4 to 20 acres. Batteries of basins, are rotated through an 18-day cycle, consisting of filling to a depth of 4 feet for six days, draining for six days, and drying for six days to maintain aerobic soil conditions and to prevent insect infestations. On this rotational basis, the capacity for recharge is 200 mgd. To maximize conservation of storm water, all basins are flooded during storms, yielding a short-term capacity for ground water recharge of about 600 mgd.

Each year, about 180,000 acre-feet of water must be percolated into the ground water basins to replace pumped water. Of this, about 60,000 acre-feet consists of captured runoff, subsurface lateral flow into the basin, and water that has risen to the surface in an adjacent ground water basin. The remaining 120,000 acre-feet consists of reclaimed waste water and imported surface supplies. The total reclaimed water input to the ground water is presently 27,000 acre-feet per year. The total amount of reclaimed water recharged into Montebello Forebay since 1962 is about 300,000 acre-feet.

The present practice of ground water recharge includes dilution of reclaimed water with imported surface supplies at a ratio of two parts imported to one part reclaimed water. This dilution criterion was intended to consistently produce ground water with less than 10 mg/L nitrate-nitrogen. When subsurface inflow and storm water are considered, the percentage of reclaimed water input to the ground water basin is about 15 percent.

Los Angeles County Flood Control District began monitoring wells surrounding the spreading ground in the mid-1950s. In 1972, an intensive monitoring program was established as a joint effort by the Los Angeles County Sanitation District and the Central and West Basin Water Replenishment District. The purpose of the intensive monitoring program is to characterize the quality of water withdrawn from the wells. Intensively monitored test wells are located at distances varying from zero to 4 miles hydrologically downstream from the nearest spreading grounds. Control wells are located hydrologically upstream of the spreading grounds. Samples of replenishment water and well water are analyzed for TDS, hardness, nitrates, trace metals, COD, chlorinated hydrocarbons, radioactivity, and bacteria. Virus samples are collected at the three treatment plants and at one well. Carbon chloroform extract samples have been collected at the same well and and at two of the three treatment plants.

Table 12 summarizes quality characteristics of the reclaimed water at two of the plants.

Viruses have been isolated in chlorinated secondary effluents from two of the three treatment plants, but have not been detected in the recharged ground water. Carbon chloroform extract (CCE) samples collected from the shallowest test well indicated that the CCE in ground water is consistently below the former drinking water limit of 0.7 mg/L, which was established in 1962 by the U. S. Public Health Service. A report on the project concluded that because this well provided the worst possible case in terms of contamination, the percolation system provided excellent inactivation of viruses and protection against organic contamination of the surrounding well system /36/. Monitoring for specific trace organic contaminants was not possible at the time of this report. The CCE procedure is now known to be a poor substitute for analysis of specific chemicals.

Table 12

AVERAGE MUNICIPAL EFFLUENT CHARACTERISTICS
AT WHITTIER NARROWS AND SAN JOSE CREEK*

Constituent	Concentration (mg/L) Whittier Narrows	Concentration (mg/L) San Jose Creek
BOD	4	4.4
SS	7	8
TDS	597	687
MBAS	0.1	0.13
pH	7.0	7.1
Cl	93	154
Na	130	150
B	0.56	0.71
Fl	1.02	0.44
Cu	0.05	0.01
Fe	0.12	0.09
Mn	0.02	0.02
Cd	0.006	0.012
Cr	0.03	0.02
Pb	0.026	0.024
Se	0.007	0.006
Ag	0.004	0.002
Zn	0.064	0.062
As	0.013	0.012
CN	0.02	0.024
Hg	0.0002	0.0003
Ni	0.13	0.02
NH_3-N	1.5	4.3
NO_3-N	14.4	12.3
NO_2-N	0.09	0.17
Org-N	2.1	1.8
Total N	17.8	18.6
Total PO_4 as PO_4	20	27
SO_4	113	107
Total Coliform MPN/100 mL	42	2.4
Fecal Coliform MPN/100 mL	10	2.0
SAR	55%	---
Oil and Grease	1.2	1.2
Phenolic compounds	0.006	0.0004
Total Pesticides	0.16	0.16

* From Reference 26.

The epidemiologic portion of the Montebello Forebay Health Effects Study has been completed and the final report published /37/. The investigation failed to conclusively demonstrate adverse health effects in the human population consuming reclaimed water in the study area. However, there was some correlation between reclaimed water use and adverse health effects.

Eastern Municipal Water District, Hemet

Since 1965, Eastern Municipal Water District has been operating a demonstration project to determine the feasibility and safety of recharging ground water basins with treated secondary effluent (activated sludge). The treated effluent has been spread in percolation basins both for disposal and for replenishment of the ground water basin. About 1.5 mgd is being recharged /26/.

The recharge area, 4 miles east of the plant, consists of 10 ponds covering about 16 acres. The basins are filled on a rotational basis; maximum infiltration rates are achieved by following a fill, drain, and dry regime on a 4-day cycle. When longer cycles were tried, clogging problems during the fill portion of the cycle resulted from algae growth stimulated by the high nutrient concentrations in the reclaimed water /26/.

Monitoring facilities consist of 10 wells, a network of piezometer holes drilled to various depths, and a shallow test pan unit for sampling under one of the basins. Average municipal effluent characteristics are shown in Table 13. The recharged water is primarily used for agricultural irrigation.

Table 13

AVERAGE MUNICIPAL EFFLUENT
CHARACTERISTICS AT HEMET, CALIFORNIA*

Constituent	Concentration (mg/L)
BOD	15-25
SS	15-20
TDS	700
Na	145
Cl	114
pH	7.6
Hardness (as $CaCO_3$)	208
Ca	75
Mg	12
K	19
NH_4	15
NO_3	24
CO_3	0
HCO_3	259
SO_4	131
Fl	0.8
B	0.7

* From Reference 26.

Hollister

Ground water quality changes at a rapid infiltration site in Hollister, California, were studied for a year, beginning in 1976 /38,39/. The soil, derived from alluvial deposits, ranges in texture from gravelly sandy loam to coarse sand and gravel. Primary treated effluent had been applied to the land for approximately 30 years.

Analyses of chemical oxygen demand (COD), biological oxygen demand (BOD), and total organic carbon (TOC) indicate effective adsorption and decomposition of organic matter.

After percolation through 22 feet of unsaturated soil, reductions noted were:

COD	93 percent
BOD	96 percent
TOC	96 percent

Results of the Hollister study were:

° Total nitrogen concentrations in the effluent were higher than in the percolated water.

° Total phosphorus levels were reduced by 30 percent after percolation through 22 feet.

° Fecal coliform removal approached 99 percent after waste water percolated 22 feet.

° TDS concentrations ranged from 1 200 to 1 300 mg/L in both effluent and shallow ground water.

° Sodium and potassium concentrations were the same in effluent and shallow aquifers.

° Sulfate concentrations in effluent and shallow ground water were lower than in most of the potable water wells serving the city of Hollister.

° Suspended solids in the primary effluent averaged 274 mg/L. After filtering through 22 feet of soil, 95 percent of the suspended solids were removed.

° Poor boron renovation efficiencies were reported. Only 14 percent retention was achieved by the surface soil. Boron concentrations in the percolated water were similar to the effluent concentrations.

° The concentration of manganese in the shallow aquifer was much higher than that recorded in the waste water effluent, indicating the solubilization of soil manganese by waste water effluent /39/. The elevated concentrations of manganese suggest the ground water may have been anaerobic. Lowered pH of the percolated water supports this hypothesis. However, no dissolved oxygen data were available for confirmation.

The pattern of pollutant removals experienced in the Hollister project may qualitatively reflect waste water interactions with soil. However, because Hollister effluent received only primary treatment, removal rates would not be equivalent to removals expected using higher quality effluent.

Chino Basin

This demonstration project is investigating rapid infiltration for treatment and reuse of waste water in the Chino basin and providing information on the fate of trace organics in ground water recharge /40/.

Ground water recharge has been practiced in the Chino basin since 1895, primarily with storm water. Surface spreading of effluent has occurred at Chino Basin Municipal Water District Regional Plant No. 1 in Ontario and is occurring in Fontana.

On April 27, 1977, the Chino Basin Water Conservation District began spreading secondary effluent from Regional Plant No. 1 at Ely Basin No. 3, a storm water recharge basin fed by the West Cucamonga Channel. A total of 330 acre-feet of effluent was applied in 1977 and 160 acre-feet in 1978.

Water supply within the Chino basin consists of about 75 percent ground water and 25 percent imported water. Withdrawal of ground water from basin storage has been restricted to the safe yield of 140,000 acre-feet per year, 38 percent of which can be for domestic supplies.

To characterize waste water quality and to establish baseline ground water quality, a small-scale monitoring program was initiated in the summer of 1979. Among the findings and conclusions of the study were:

- ° Soil permeability is not a limiting factor for rapid infiltration in the area surrounding Regional Plant No. 1.
- ° A total of 27 organic compounds were positively identified in waste water and ground water sampled.
- ° Of the organic compounds identified in unchlorinated waste water, six (dichloromethane, chloroform, benzene, tetrachloroethylene, toluene, and ethyl benzene) are on the list of Environmental Protection Agency priority pollutants. Concentrations of these compounds ranged from 2 to 18 ug/L.
- ° Waste water chlorination appeared to significantly increase the concentrations of three priority pollutants (dichloromethane, chloroform, and toluene).
- ° Ground water concentrations of fecal coliforms indicate some bacterial contamination of the sampled ground water. The ground water is, however, suitable for irrigation.
- ° The soil is highly efficient in removing pathogenic bacteria and viruses. At application rates below 12 inches per day, with long drying periods (more than 7 days), and at 10 feet or more depth to ground water, the removals of pathogenic bacteria and viruses should be complete.

Lodi

A waste water reclamation project employing land spreading was monitored for 2-1/2 years in Lodi, California. The most probable number (MPN) of coliform organisms was consistently reduced from 1.8×10^5 per 100 mL, in the secondary effluent, to less than one per 100 mL by 4 to 5 feet of soil percolation /41/. The average percolation rate was 0.58-foot per day in coarse textured Hanford sandy loam. The tendencies were for sodium and potassium concentrations to decrease and for calcium and magnesium concentrations to increase as the water percolated through the soil.

Other California Projects

Two coastal cities, Oceanside and San Clemente, have been recharging waste water for the dual purposes of ground water basin replenishment and as a barrier to seawater intrusion /26/.

Oceanside has been recharging waste water since 1958. It is pumped 3 miles inland, where it is recharged by percolation. Extraction wells are located a half-mile downstream.

With this percolation-extraction system, no renovated water volumes of any significance are thought to migrate directly into the native ground water. The extracted water is used for irrigation.

San Clemente entered into an agreement with Camp Pendleton in 1968 to utilize a shared river basin to recharge reclaimed waste water. Recharged water was to act as a seawater intrusion barrier. Recharge is accomplished by percolation through a 5-acre diked area in the dry riverbed. The recharged water migrates downstream toward the ocean, where it forms the seawater barrier. Use of the renovated water would be for irrigation only.

The U. S. Marine Corps, Camp Pendleton, has always relied solely on ground water for its water supply and hopes to avoid reliance on external sources by proper management of the ground water basins. The basins are continually recharged with reclaimed waste water, stored surface runoff, and local precipitation when available. The effluent used is secondary treated by trickling filters; the plant capacity is 4 mgd. Although the recharged water enters the potable aquifer, it forms a layer at the top of the ground water basin and has little chance to mix with water in the deeper, potable zone, which is 150 to 300 feet. During the rainy season, natural precipitation and runoff tend to carry the upper zone of the aquifer, which contains most of the treated effluent, into the ocean. The amount of recharged water reaching the potable zone is estimated to be quite low.

Chapter 3. HEALTH CONCERNS IN GROUND WATER RECHARGE USING RECLAIMED WASTE WATER

In 1978, the State Department of Health Services adopted waste water reclamation criteria for crop and landscape irrigation and for recreational and landscape impoundments /42/. These regulations established acceptable levels of several constituents in reclaimed water. The regulations also specify the minimum necessary reliability features for waste water reclamation facilities. No specific standards have been set for recharge of ground water basins, but the water used would probably be required to meet at least potable water quality standards. In the case of trace organics, criteria might exceed standards set for potable water. The Panel on Quality Criteria for Water Reuse, of the National Research Council, addressed the establishment of quality criteria for reclaimed water /43/. The panel found that drinking water regulations had not been established to evaluate the suitability of highly contaminated water for drinking. The panel saw a need for such standards.

In developing the standards, the panel endorsed the concept that drinking water should be taken from the best possible source, and that alternative sources should be evaluated to identify the best alternative. The panel also proposed assessment criteria for accomplishing the evaluations through this approach. Any water, regardless of source, could be used for drinking if it were demonstrated to be the best alternative.

The three main areas of health concern are: microbial, trace metal, and trace organic contaminants.

Microbial Contaminants

A total of 192 outbreaks of water-borne disease, affecting 36,757 people, were reported in the United States from 1971 to 1977. Almost half of the outbreaks and illnesses were caused by use of untreated or inadequately treated ground water. The source of these illnesses is primarily water-borne viruses and bacteria /44/, indicating a critical need to remove microbial contaminants in waste water before recharge occurs.

Viruses

Virus inactivation or removal in waste water is critical, due to the seriousness of viral diseases. One study indicates that sewage contains from 2 to more than 1,000 infectious viruses per 100 mL, with peak levels occurring in late summer and early fall /45,46/. Researchers are primarily concerned with viruses that can survive the high acid conditions of the stomach and the bile of the duodenum. These viruses, of fecal origin, are capable of infecting humans through water supplies.

Picornaviruses comprise the largest and most important group of human pathogens /47/. Picornaviruses are divided into two groups -- enteroviruses (found in the intestines) and rhinoviruses (found in the upper respiratory tract). The enteroviruses, which can survive the gastrointestinal tract, can be subdivided into polio, coxsackie, and echo viruses. Another group of water-borne viruses spread by fecal contamination is hepatitis A and B.

Viruses transmitted by the alimentary route are, in general, more resistant to inactivation by environmental conditions than are the respiratory viruses, which are spread directly from infected to susceptible individuals /47/. Enteroviruses, are therefore, more resistant to disruption by sewage treatment processes. Factors that affect virus survival include pH, temperature, radiation, chemical reagents, stabilizing organic matter, and cation stabilization. Different viruses have different tolerances to these factors.

Detection of viruses is very difficult. They are extremely small and cannot be recovered and measured using classical analytical methods. One established means of recovering viruses from aqueous solutions is to change the charge on the virus particle by changing the water chemistry, cause the virus to adsorb on a surface, remove the excess water, release the virus by reversing the charge, infect living tissue culture, and observe visible cytopathic effects for identification /48/. This complex process is subject to numerous interferences that limit the reliability of the test. The techniques for sample concentration, the host cell system, and the type of culture technique used are all selective to some degree. No universal procedure or system is yet recognized for the cultivation of all viruses. It is likely, therefore, that in many investigations of viruses in waste water, not all the viruses present are being detected.

Bacteria, Protozoa, Helminths

Besides virus, other microbial pathogens associated with waste water include bacteria, protozoa, and helminths. Detection of these organisms in waste water is relatively simple, compared to virus detection. Also, removal of these organisms is readily accomplished through conventional treatment processes.

Inorganic Contaminants

The quantities of inorganic constituents in sewage effluents depend on several factors, but mainly on the type of waste -- domestic or industrial -- and on the degree of treatment that the waste water receives /50/. The following is a discussion of specific inorganic contaminants of health concern.

Nitrates

Nitrates are of health concern because of their capacity to cause infant methemoglobinemia, a disease resulting in insufficient oxygen carrying capacity of the blood. Typically, cases of this disease are associated with water used to prepare infant formula. Incidence of the disease is rare when concentrations of nitrates are below 50 mg/L /49/.

Sodium

Sodium in drinking water supplies may be harmful to persons suffering from heart, kidney and circulatory system diseases. The recommended sodium limit is 20 mg/L in water consumed by persons on severely restricted sodium diets. Sodium concentrations up to 270 mg/L are acceptable for persons on moderately restricted sodium diets /49/.

Trace Metal Contaminants

In recent years, the discharge of trace metals from waste water has been of great concern to both regulatory agencies and dischargers. Because of the possible ecological effects of these elements in receiving waters and because of concern for human safety, Federal regulations have been promulgated to control release of these agents into the environment /8,9/.

Trace Organic Contaminants

Among the many sources of trace organics in water supplies are industrial wastes, domestic wastes, and nonpoint sources such as agricultural and landfill runoff, decayed plant and animal matter, and atmospheric contamination /51/.

In high concentrations, organic compounds in water supplies can cause acute toxicity; however, the greatest concern is that very low levels of some agents may be capable of causing chronic long-term effects such as cancer.

Because treated fresh water contains organic agents, treated waste water can contain not only organic compounds present in the original water supply, but also compounds added to the waste stream and produced during treatment. For reclaimed waste water to be rendered fit for potable consumption, concentrations of harmful organics would have to to be reduced below levels at which adverse effects would be expected.

Chapter 4. EFFECT OF WASTE WATER TREATMENT PROCESSES IN REMOVING CONSTITUENTS OF HEALTH CONCERN

The effects of different waste water treatment processes on viruses, microorganisms, inorganic elements, and trace organics are discussed in this chapter.

Effect on Viruses

Waste treatment processes are capable of greatly reducing virus populations, but different treatments yield varying reductions. The effectiveness of virus removal in the waste water treatment processes depends on the quality of the influent water and the type of virus.

One way of evaluating treatment efficiency is to closely follow a selected indicator virus. Suitable indicator viruses should be "relatively" stable under natural conditions, meaning that the virus should be neither stable nor labile, but indicative of general virus content. The virus should have a high frequency in human population and be present in fecal matter. For employee safety, it must have low virulence. A sensitive method must be available for detecting the presence of the indicator. Polioviruses 1,2,3, bacteriophage F2, and coxsackie viruses generally meet these criteria and are, therefore, most commonly used as indicators.

Primary Treatment

Primary treatment (removal of suspended solids) results in generally ineffective removal of viruses /52/.

Secondary Treatment

Biological treatment processes are processes in which the metabolic activities of bacteria and other microorganisms are harnessed to break down complex organic materials into simple, more stable substances. During biological treatment, organic material is converted into bacterial cell mass. Viruses are entrapped in this biomass and are removed. The most efficient type of biological secondary treatment process commonly employed is activated sludge.

The activated sludge process employs rapid mixing and aeration of raw or settled waste water. These conditions optimize growth and reproduction of aerobic bacteria and other organisms. In the process the organic materials in the waste water are consumed as food. Following treatment, the bacterial biomass is allowed to settle out as sludge; viruses are absorbed by and adsorbed on suspended solids and are removed in the settling process.

Removal of bacteriophage F2 through the activated sludge process was 98 percent /53/; for polio 1,2,3 (Sabin), removal ranged from 76 to 90 percent /52,55/. The microbiology of the activated sludge process is thoroughly discussed in a recently published review that examines 10 years of literature /56/.

Disinfection

In waste water treatment, disinfection is the process of killing or inactivating pathogenic microorganisms to render the treated water safe for contact by humans. Disinfection is the final treatment process before waste water effluent is released into the environment. (Processes employed to neutralize the disinfecting agent are considered part of the disinfection process.)

Historically, chlorine has been the most used disinfecting agent, but ozone use is increasing due to concern over halogenated organic compounds that may be created by the chlorination process. Methods of disinfection are discussed below.

Chlorination. Chlorine is by far the most commonly used disinfectant in waste water treatment. It is used in three main forms: chlorine gas, hypochlorite, and chlorine dioxide.

A controversy exists in the waste water treatment industry over which form is best for effluent disinfection. Each type reacts somewhat differently with waste water constituents. Also, each type has a different level of effectiveness in virus inactivation and requires different amounts of exposure to the waste water. Despite some differences in the mechanism of action of the different chlorine forms, chlorine in any of these forms is a highly effective disinfecting agent.

Culp reported no surviving plaque-forming units (PFUs) in chlorinated effluent from South Lake Tahoe's sewage treatment plant /57/. Cramer, et al, found 100 percent removal of polio 3 virus in their study of chlorinated effluent /58/.

Ozonation. Ozone is a more powerful oxidizing agent than chlorine and is more effective than chlorine at inactivating virus. The drawbacks are higher cost and the lack of residual effect on the treated effluent.

In studies of the effectiveness of ozone in virus removal, bacteriophage F2 removal was 100 percent /59/, coxsackie B3 removal was 99.9 percent /60/, and polio 1 and 2 were 99.9 percent inactivated /60,61/.

In addition to effective virus removal, Gurguis, et al, found that ozonation of a secondary effluent reduced the molecular weights of the organic substances present and improved their biodegradability, which, in turn, improved the performance of a granular-activated carbon adsorption column /62/. The theory was that bacteria were responsible for much of the organic removal in an activated carbon column.

In the 1975 Pomona Virus Study, an ozone dosage of 10 mg/L for 18 minutes' contact time was observed to reduce active polio type 1 virus concentration by 99.90 percent, when the predisinfection virus concentration was 7.2×10^4 PFU per 100 gallons. In another system configuration, the predisinfection virus concentration was higher (5.6×10^6 PFU/100 gallons). The same ozone dosage and contact time resulted in a 99.997 percent reduction, indicating that virus removal efficiencies increase with increasing concentrations /63/.

Tertiary Treatment

The following is a discussion of the effects of three advanced waste water treatment processes in removing virus.

Coagulation-Sedimentation. The coagulation-sedimentation process is efficient at removing virus. Efficiency varies, however, depending upon whether alum or ferric chloride is the coagulant used.

Malina found removal through the coagulation process to be 99 percent of the initial virus concentration; turbidity was decreased by 90 percent /64/. In another study, no viable polio 1 viruses were recovered after lime clarification treatment /65/.

In the Pomona Virus Study, coagulation and sedimentation using alum and an anionic polymer reduced polio Type 1 concentrations by an average of 95 percent in 25 seeding experiments /63/.

In 1978, the Environmental Protection Agency published the results of an 18-month study of the safety of treated municipal waste water for discharge upstream of drinking water intakes /66/. The plant was the Agency's Washington, D.C., Blue Plains Pilot Plant. The treatment system included: lime clarification, nitrification, dentrification, carbon adsorption, coagulation with alum and polymer, filtration, and chlorination. Performance results using three separate sampling periods and three stages of treatment indicated no animal viruses in the final effluent.

Table 14 presents virus removal data for Water Factory 21. Virus in the supply water, which is activated sludge effluent, was effectively removed by the

Table 14

SUMMARY OF VIRUS RESULTS
SAMPLES COLLECTED MARCH 1980-APRIL 1981+

Date of Sample	Virus Concentration (MPNCU/Litre)*											
	Influent		Chemical Effluent		Granular Activated Carbon Influent		Granular Activated Carbon Effluent		Chlorinated Effluent		Reverse Osmosis Effluent	
	BGM	RD	BGM	RD	BGM	RD	BGM	RD	BGM	RD	BGM	RD
3/6/80	0.11	0.07	--	--	--	--	--	--	--	--	ND	ND
3/14/80	0.66	0.44	--	--	--	--	--	--	--	--	ND	ND
3/20/80	ND	ND	--	--	--	--	--	--	--	--	ND	ND
4/4/80	ND	ND	--	--	--	--	--	--	--	--	ND	ND
4/8/80	ND	ND	--	--	--	--	--	--	--	--	ND	ND
4/16/80	ND	ND	--	--	--	--	--	--	ND	ND	--	--
4/23/80	ND	0.10	--	--	--	--	--	--	ND	ND	--	--
5/1/80	ND	ND	--	--	--	--	--	--	ND	ND	--	--
5/21/80	ND	0.06	--	--	--	--	--	--	ND	ND	--	--
5/29/80	0.05	0.26	--	--	--	--	--	--	ND	ND	--	--
6/3/80	ND	ND	--	--	--	--	--	--	ND	ND	--	--
6/19/80	0.10	0.03	--	--	--	--	--	--	ND	ND	--	--
6/24/80	ND	ND	--	--	--	--	--	--	ND	ND	--	--
7/9/80	ND	ND	--	--	--	--	--	--	ND	ND	ND	ND
7/17/80	0.10	0.03	--	--	--	--	--	--	--	--	ND	ND
7/23/80	ND	ND	--	--	--	--	--	--	ND	ND	ND	ND
8/26/80	0.97	0.58	--	--	--	--	--	--	ND	ND	ND	ND
9/4/80	0.97	0.61	--	--	--	--	--	--	ND	ND	0.04	ND
9/11/80	ND	ND	--	--	--	--	--	--	ND	ND	ND	ND
10/14/80	0.08	ND	ND	ND	ND	ND	--	--	--	--	--	--
10/15/80	ND	ND	ND	ND	ND	ND	--	--	ND	ND	--	--
10/16/80	ND	0.22	ND	ND	ND	ND	--	--	--	--	--	--
10/17/80	1.3	1.3	ND	ND	ND	ND	--	--	--	--	--	--
10/22/80	--	--	ND	ND	--	--	ND	ND	--	--	--	--
10/23/80	--	--	ND	ND	--	--	ND	ND	--	--	--	--
10/28/80	--	--	ND	ND	--	--	ND	ND	--	--	--	--
10/30/80	ND	ND	ND	ND	--	--	ND	ND	--	--	--	--
10/31/80	ND	ND	--	--	--	--	--	--	ND	ND	--	--
11/6/80	ND	ND	--	--	--	--	ND	ND	--	--	--	--
11/7/80	0.06	ND	--	--	--	--	--	--	ND	ND	ND	ND
11/11/80	0.02	ND	--	--	--	--	--	--	--	--	--	--
11/12/80	ND	0.02	--	--	--	--	--	--	--	--	--	--
11/26/80	--	--	--	--	--	--	--	--	ND	ND	ND	ND
11/27/80	ND	ND	--	--	--	--	--	--	--	--	--	--
12/4/80	ND	ND	--	--	--	--	--	--	ND	ND	ND	ND
2/25/81	0.06	0.06	--	--	--	--	--	--	ND	ND	ND	ND
3/12/81	0.06	0.06	--	--	--	--	--	--	ND	ND	ND	ND
3/19/81	ND	ND	--	--	--	--	--	--	ND	ND	ND	ND
4/9/81	--	--	--	--	--	--	--	--	--	--	ND	ND
4/23/81	ND	ND	--	--	--	--	--	--	--	--	ND	ND

+ From Reference 30.
* Samples were inoculated into BGM and RD liquid cell cultures and the cultures examined for cytopathic effects. MPNCU/Litre = Most Probable Number of Cytopathic Units per litre.
-- = Not sampled.
ND = Not detected.

lime treatment process. Measurements were made to determine virus removal capability of granular activated carbon and reverse osmosis processes, which follow the lime process in the treatment train. However, the near complete absence in the influents to these processes does not yield a clear picture of their effect.

Activated Carbon. Although some virus removal has been observed with activated carbon treatment, the removal efficiency depends on pH and type of carbon. It is not primarily used for virus removal.

In the Pomona Virus Study, fresh activated carbon removed an average of 91 percent of polio Type 1 virus in 9 seeding experiments /63/.

Reverse Osmosis. In Las Gallinas, California, a pilot-scale reverse osmosis plant was used to demineralize activated sludge-treated secondary effluent. Table 15 presents virus removal data resulting from the project. Product water had concentrations of virus 2 or 3 orders of magnitude lower than feedwater /67/.

Table 15

COLIFORM, COLIPHAGE, AND POLIOVIRUS RECOVERY FROM THE LAS GALLINAS WATER RECLAMATION PLANT[†]

Date	Coliform*	Coliphage*	Poliovirus**
Feedwater			
5/20/77	4.3×10^6	4.3×10^5	2.2×10^5
5/31/77	4.3×10^6	2.3×10^5	2.0×10^5
6/10/77	9.3×10^5	2.3×10^5	1.7×10^5
6/17/77	9.3×10^5	4.3×10^5	2.3×10^5
6/24/77	9.3×10^5	2.1×10^5	2.4×10^5
Product Water			
5/20/77	9.3×10^3	2.3×10^3	6.8×10^2
5/31/77	4.3×10^4	9.0×10^2	2.5×10^1
6/10/77	9.3×10^3	2.1×10^2	3.5×10^2
6/17/77	9.3×10^3	2.1×10^2	2.5×10^2
6/24/77	4.3×10^3	9.0×10^1	1.1×10^1

† From Reference 67.
* MPN/100 mL.
** PFU/100 mL.

Effect on Other Microorganisms

Bacteria can be killed or inactivated by the same means of disinfection used to destroy virus /68/. However, parasite eggs, protozoan cysts, and other encapsulated organisms can survive the disinfection process and can be effectively removed from waste water only by flocculation and sedimentation, and in some cases only by filtration. Therefore, in considering waste water quality for reuse, it must be assumed that to eliminate all encapsulated pathogens, flocculation, sedimentation, and filtration processes would be required in addition to disinfection.

Effect on Inorganic Contaminants

Following is a discussion of water treatment processes on removals of specific inorganic contaminants of health concern.

Nitrate

Conventional waste water treatment processes increase nitrate concentrations. This phenomenon is due to oxidation of organic nitrogen, ammonia, and nitrites that occurs during treatment. The result is a water lower in organic nitrogen, ammonia, and nitrites, and higher in nitrates, as compared to the influent waste stream.

Reverse osmosis can be used to reduce nitrate concentrations. As an example, Water Factory 21, discussed in Chapter 2, reduced nitrate concentrations from 7.7 to 3.3 mg/L by application of reverse osmosis /29/.

Sodium

Sodium concentrations are not affected to a significant degree by conventional waste water treatment process. However, reverse osmosis can greatly affect sodium concentrations. The Las Gallinas reverse osmosis plant reduced sodium concentrations from 156 to 40 mg/L in one test period /67/. At Water Factory 21, the geometric mean sodium concentration was reduced from 225 to 22 mg/L as a result of reverse osmosis /30/.

Trace Metals

Chen, et al, investigated the Hyperion Treatment Plant in Los Angeles, California, for effectiveness of trace metal removal /69/. They concluded that secondary treatment was effective in removing trace metals except for nickel, manganese, and lead.

Pahren and Ulmer investigated trace metal removal by advanced waste water treatment facilities /70/. Included were the Environmental Protection Agency's Blue Plains pilot plant, Water Factory 21, and the Pomona Research Facility. The objective of the screening was to determine if any element not ordinarily monitored might be present in the effluent at a level that would be a health concern if the water were used for drinking. Table 16 summarizes elements that were not detected in the effluent measurements.

The results of this study showed that, with one exception, advanced waste water treatment reduces concentrations of all measured elements to below the limits set by the Environmental Protection Agency's National Interim Primary Drinking Water Regulations. The exception was lead, which at Blue Plains had a value of 63 parts per billion (ppb). The drinking water limit for lead is 50 ppb. Table 17 compares the quality of the effluents studied to the drinking water regulations.

At the Pomona plant, the influent and effluent were measured for trace levels of metals so that removal rates could be determined. Two parallel systems were sampled. One system consisted of

Table 16

ELEMENTS NOT DETECTED IN ADVANCED WASTE WATER TREATMENT EFFLUENTS

Element	Detection Limit ppb	Element	Detection Limit ppb
Scandium	0.1% Ca	Germanium	0.1
Silicon	5,000	Palladium	0.1
Indium	0.2	Tellurium	0.7
Cesium	2	Lanthanum	2.5
Tungsten	0.3	Platinum	0.3
Niobium	0.1	Bismuth	0.3
Ruthenium	1	Zirconium	1
Rhodium	1	Cerium	20
Praseodymium	18	Neodymium	16
Promethium	13	Samarium	12
Europium	11	Gadolinium	9
Terbium	8	Dysprosium	7
Holmium	6	Erbium	5
Thulium	3	Ytterbium	3
Lutecium	3	Hafnium	3
Tantalum	3	Rhenium	3
Osmium	3	Iridium	3
Gold	3	Mercury	3
Polonium	3	Astatine	3
Francium	3	Radium	3
Actinium	3	Thorium	3
Protactinium	3	Uranium	3
Neptunium	3	Plutonium	3

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* From Reference 70.

Table 17

COMPARISON OF ADVANCED WASTE WATER TREATMENT EFFLUENTS WITH DRINKING WATER STANDARDS*

Element	Minimum (ppb)	Median (ppb)	Maximum (ppb)	NIPDWR** (ppb)
Arsenic	<0.5	2.3	9.5	50
Barium	<2.5	35	77	1,000
Cadmium	<0.1	<0.1	5.0	10
Chromium	<0.1	0.7	12	50
Lead	<0.1	2.7	63	50
Mercury	<3	<3	<3	2
Selenium	<1	<1	2.5	10
Silver	<1	<1	2.4	50

---

* From Reference 70.
** National Interim Primary Drinking Water Regulations.

coagulation, sedimentation, filtration, chlorination, and carbon adsorption. The other had two carbon adsorption steps, with intermediate chlorination. The elements investigated were reduced in concentration from 2 to 100 percent; exceptions were calcium, vanadium, manganese, iron, and arsenic (see Table 18).

Table 18

PERCENT REMOVAL OF ELEMENTS
AT POMONA CALIFORNIA
WATER RECLAMATION PLANT*

Element	Carbon System	Chemical Coagulation System
Potassium	8	3
Calcium	0	0
Vanadium	0	0
Chromium	78	99
Manganese	0	0
Iron	0	0
Nickel	42	44
Copper	90	88
Zinc	42	21
Molybdenum	33	63
Lead	92	99
Titanium	67	67
Rubidium	29	52
Strontium	3	2
Tin	67	100
Barium	20	18
Arsenic	21	0

* From Reference 70.

Coagulation and sedimentation have been found to be especially effective processes for reducing concentrations of trace metals. Table 19 presents data from Water Factory 21 demonstrating this effect /30/. The 95 percent CI indicates the range within which the true mean value the percent removal should fall 95 percent of the time.

Table 20 depicts metal removals resulting from granular activated carbon treatment of waste water at Water Factory 21 /29/. Removal efficiencies of lead, copper, and chromium were substantial.

Table 21 demonstrates statistically significant removals of trace metals by reverse osmosis at Water Factory 21. Removal efficiencies ranged from 56 to 97 percent for these elements.

Effect on Trace Organics

At Water Factory 21, in Orange County, the effects of individual treatment processes in removing organic contaminants have been examined. The results of that study are presented below. Overall plant performance is then discussed.

Chemical Clarification

Water Factory 21 employs chemical clarification with lime as the primary coagulant. Removal of trace organics through this process is effective for some compounds and ineffective for others. Table 22 presents data from the Water Factory 21 study showing removals as high as 71 percent for Di-n-butyl phthalate /29/.

Air Stripping

Table 23 demonstrates the effectiveness of air stripping in removing volatile organic and aromatic compounds at Water Factory 21. The air blowers installed for ammonia removal were not in operation during the period of sampling. Removals ranged from 43 to 97 percent for these compounds; compounds of lower volatility, such as PCB (Arclor 1242) and 2-Methylnaphthalene were not removed.

Activated Carbon

The effect of activated carbon treatment in removal of trace organics is summarized in Table 24. Removal efficiencies ranged from 56 to 99 percent. Removals of trihalomethane were relatively poor, with high variability in effluent concentrations. Trihalomethane removal efficiencies declined rapidly as a function of time between carbon regenerations.

Reverse Osmosis

Table 25 shows removals of trace organics by reverse osmosis. Removal efficiencies were highest for the halogenated methanes.

Overall Plant Performance

Table 26 demonstrates overall removal rates of trace inorganic constituents after various stages of treatment at Water Factory 21. Lime treatment and reverse osmosis generally had the greatest effects in removing these elements.

Table 27 shows removal rates for organic Priority Pollutants and Table 28 shows removal rates for non-Priority Pollutant organic compounds at Water Factory 21.

Table 19

STATISTICALLY SIGNIFICANT POLLUTANT REMOVALS BY
LIME TREATMENT COMPARED WITH OVERALL REMOVAL
JANUARY 1980 TO APRIL 1981[†]

				Percentage Removal			
				Lime		Overall	
Pollutant	Geometric Mean Influent Concentration*	Spread Factor S‡	Detection Limit*	Mean	95% CI	Mean	95% CI
Barium	94	1.71	1	62	50-71	59	42-71
Cadmium	9	2.36	0.1	80	68-87	85	77-91
Chromium	33	1.65	1	76	67-83	88	82-92
Copper	49	1.70	1	81	74-86	89	84-92
Iron	114	1.68	1	84	77-88	76	69-81
Lead	5	2.06	1	89	63-97	89	60-97
Manganese	56	1.49	0.1	98	96-99	94	90-96
Nickel	77	1.70	1	65	56-71	79	74-83
Silver	2	1.95	0.1	76	62-85	78	63-87

---

†From Reference 30.

*Geometric mean concentration and limit in µg/L.

‡Spread factor is the antilog of the standard deviation of the geometric mean concentration.

Table 20

REMOVAL OF HEAVY METALS BY GRANULAR ACTIVATED CARBON†

Contaminant	March 1978 to January 1979 Influent Concentration*	 Effluent Concentration	 Average Percent Removal (95% CI)
Ag	0.77	0.69	10 (-250 to 77)
Ba	7.8	7.4	5 (-150 to 64)
Cd	7.2	9.5	-32 (-210 to 43)
Cr	5.6	3.1	45 (-3 to 70)
Cu	36	16	56 (-85 to 89)
Fe	28	42	-50 (-530 to 64)
Mn	1.3	1.7	-35 (-270 to 51)
Pb	3.1	1.0	68 (-780 to 99)

---

†From Reference 29.

*Geometric mean concentration in μg/L.

Table 21

STATISTICALLY SIGNIFICANT POLLUTANT REMOVALS BY REVERSE OSMOSIS (Including Decarbonation) JANUARY 1980 TO APRIL 1981+

Pollutant	Geometric Mean Influent Concentration†	Spread Factor S*	Detection Limit†	Percentage Removal Mean	 95% CI
Barium	35	2.04	1	97	95-98
Cadmium	1.6	3.11	0.1	96	91-98
Chromium	2.4	2.34	1	65	25-84
Copper	8.9	1.57	1	56	39-68
Iron	38	2.25	1	93	86-96
Lead	4.1	1.54	1	84	67-92
Manganese	2.5	2.45	0.1	91	74-97
Mercury	0.7	1.83	0.5	65	56-71
Nickel	24	1.86	1	76	62-85
Silver	0.4	3.38	0.1	63	15-84

+From Reference 30.

†Geometric mean concentration and limit in μg/L.

*Spread factor is the antilog of the standard deviation of the geometric mean concentration.

REMOVAL OF TRACE ORGANICS BY LIME TREATMENT*

Contaminant	March 1978 to January 1979 Influent Concentration (µg/L)	Effluent Concentration (µg/L)	Average Percent Removal (95% CI)
Di-n-butylphthalate	0.79	0.23	71 (-80 to 95)
1,2,4-trichlorobenzene	0.11	0.035	68 (2 to 90)
Bis-(2-diethylhexyl)-phthalate	11	3.8	65 (32 to 82)
Lindane	0.14	<0.05	>64
1,3-dichlorobenzene	0.16	0.10	38 (10 to 57)
Dimethylphthalate	4.8	3.1	35 (-5 to 60)
Diisobutylphthalate	4.7	3.2	32 (12 to 48)
1,4-dichlorobenzene	1.85	1.29	30 (16 to 42)
PCBs as Aroclor 1242	0.47	0.37	21 (-15 to 46)
1,2-dichlorobenzene	0.64	0.56	12 (-54 to 50)
2-methylnaphthalene	0.01	0.009	10 (-253 to 77)
Bromodichloromethane	0.53	0.56	-6 (-33 to 16)
Chlorobenzene	0.14	0.15	-7 (-80 to 36)
Dibromochloromethane	0.69	0.79	-14 (-42 to 8)
Trichloroethylene	0.74	0.86	-16 (-270 to 63)
Heptaldehyde	0.10	0.12	-20 (-132 to 38)
Naphthalene	0.033	0.041	-24 (-548 to 76)
Chloroform	3.2	4.1	-30 (-79 to 5)
1,1,1-trichloroethane	3.3	4.7	-45 (-198 to 30)
Tetrachloroethylene	1.67	2.5	-50 (-141 to 7)
p-xylene	0.015	0.023	-53 (-206 to 23)
Ethylbenzene	0.043	0.067	-56 (-202 to 20)
Styrene	0.048	0.076	-58 (-294 to 36)
Tribromomethane	0.40	0.67	-68 (-143 to -15)
1-methylnaphthalene	0.008	0.019	-138 (-510 to 8)
m-xylene	0.035	0.086	-146 (-329 to 41)

---

* From Reference 29.

Table 23

STATISTICALLY SIGNIFICANT POLLUTANT REMOVALS BY AIR STRIPPING MARCH 1978 TO APRIL 1981*

Pollutant	Geometric Mean Influent Concentration†	Spread Factor	Detection Limit†	Percentage Removal	
				Mean	95% CI
VOA Compounds					
Chloroform	4.7	1.35	0.05	81	75-86
Bromodichloromethane	0.8	1.53	0.05	91	87-94
Dibromochloromethane	0.9	1.55	0.1	81	76-85
Bromoform	0.6	2.21	0.2	67	51-78
1,1,1-Trichloroethane	3.6	2.49	0.05	95	93-97
Trichloroethylene	0.9	2.65	0.05	97	89-99
Tetrachloroethylene	2.9	2.90	0.05	95	93-97
CLSA Compounds					
1,2-Dichlorobenzene	0.6	2.44	0.01	79	68-87
1,3-Dichlorobenzene	0.2	2.02	0.01	83	74-89
1,4-Dichlorobenzene	1.4	1.59	0.01	87	83-89
1,2,4-Trichlorobenzene	0.2	2.56	0.01	50	25-67
Ethylbenzene	0.07	2.89	0.01	43	15-61
p-Xylene	0.04	2.76	0.01	50	22-68

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*From Reference 30.

†Geometric mean concentration and limit in μg/L.

Table 24

STATISTICALLY SIGNIFICANT POLLUTANT REMOVALS BY GRANULAR ACTIVATED CARBON*

				Percentage Removal	
Pollutant	Influent Concentration†	Spread Factor	Detection Limit†	Mean	95% CI
VOA Compounds[a]					
Chloroform	7.9	3.02	0.05	56	3-80
Bromodichloromethane	3.9	4.22	0.05	76	18-93
Dibromochloromethane	2.1	5.62	0.10	80	9-96
CLSA Compounds[b]					
Chlorobenzene	0.16	2.78	0.01	69	24-87
1,2-Dichlorobenzene	0.25	2.20	0.01	88	76-94
1,3-Dichlorobenzene	0.04	2.91	0.01	75	2-94
1,4-Dichlorobenzene	0.19	1.77	0.01	89	81-94
1,2,4-Trichlorobenzene	0.07	3.39	0.01	86	57-95
Heptaldehyde	0.07	3.22	0.01	71	30-88
Styrene	0.05	3.10	0.01	80	46-93
Napthalene	0.23	3.45	0.01	61	17-82
1-Methylnapthalene	0.04	2.45	0.01	75	27-91
2-Methylnapthalene	0.04	2.89	0.01	75	27-91
A/P Compounds[b]					
Lauric Acid	3.0	3.24	0.05	84	4-97
3-Hydroxylauric Acid	3.2	2.75	0.05	92	61-98
117A	17	3.12	0.05	99	86-99.9
117F	2.2	3.70	0.05	85	27-97
B/N Compounds[b]					
X11	3.3	6.7	0.10	94	56-99
X22	4.8	7.0	0.10	99	66-99.98

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*From Reference 30.

†Influent concentration and limit in µg/L.

a = Data for March 1978 to April 1981.

b = Data for August 1980 to April 1981.

Table 25

AVERAGE PERCENTAGE REMOVAL OF CONTAMINANTS BY FULL-SCALE AND PILOT REVERSE OSMOSIS SYSTEMS[†]

Contaminant	Influent Concentration*	Effluent Concentration*	Average Percent Removal (95% CI)
Chloroform	7.5	1.0	87 (81 to 91)
Bromodichloromethane	0.81	0.24	70 (53 to 81)
Dibromochloromethane	0.31	0.13	58 (27 to 76)
Tribromomethane	0.08	0.007	91 (-1 to 99)
Carbon tetrachloride	0.06	0.008	86 (-3 to 98)
1,1,1-trichloroethane	0.18	0.0083	53 (-168 to 92)
Tetrachloroethylene	0.17	0.20	-18 (-222 to 57)
Chlorobenzene	0.04	0.034	17 (-93 to 64)
Ethylbenzene	0.02	0.02	0 (-117 to 54)
m-xylene	0.02	0.02	-4 (-104 to 47)
Naphthalene	0.02	0.03	-22 (-237 to 56)
2-methylnaphthalene	0.02	0.008	60 (-36 to 88)
Dimethylphthalate	2.4	1.0	58 (4 to 82)
Di-n-butylphthalate	0.90	1.1	-22 (-337 to 66)
Diisobutylphthalate	0.33	0.23	30 (-566 to 93)
Bis-(2-ethylhexyl)-phthalate	7.8	2.9	63 (-109 to 93)
COD, mg/L	14.6	1.3	91 (89 to 92)
TOC, mg/L	7.2	2.6	64 (55 to 71)
Electroconductivity, μS/cm	1 470	156	89 (89.1 to 90)

[†] From Reference 29.

* Concentrations in μg/L unless otherwise shown.

Table 26

CUMULATIVE PERCENTAGE REMOVAL OF TRACE INORGANIC CONTAMINANTS AFTER VARIOUS STAGES OF TREATMENT JANUARY 1980 THROUGH MARCH 1981*

Contaminant	Lime	Filtration	Granular Activated Carbon	Chlorination	Reverse Osmosis Influent	Reverse Osmosis Effluent
Aluminum	70 (39-85)	64 (36-80)	42 (0-66)	60 (35-75)	55 (2-79)	92 (87-95)
Barium	68 (56-76)	68 (56-76)	59 (42-71)	48 (35-58)	56 (35-71)	98.6 (97.8-99.1)
Beryllium	-23 (-333-65)	20 (-390-87)		-37 (-470-67)	77 (-530-99)	
Cadmium	80 (68-87)	82 (71-88)	85 (77-91)	87 (82-90)	83 (68-91)	99.2 (98.7-99.6)
Chromium	76 (67-83)	80 (73-85)	88 (82-92)	92 (85-95)	93 (89-96	98 (95-99)
Cobalt	47 (-56-82)	43 (-55-79)	74 (-18-94)	70 (14-89)	53 (-128-91)	99.8 (93-100)
Copper	81 (74-86)	62 (54-69)	89 (84-92)	-212 (-336-123)	82 (77-86)	92 (90-94
Iron	84 (77-88)	10 (-27-35)	76 (69-81)	55 (43-65)	66 (48-78)	98 (96-99)
Lead	89 (63-97)	88 (56-97)	89 (60-97)	5 (-53-41)	14 (-45-49)	86 (78-91)
Manganese	98 (96-99)	90 (86-93)	94 (90-96)	92 (90-94)	97 (96-98)	99.8 (99.4-99.9)
Mercury	61 (-88-92)	-24 (-142-36)	-18 (-150-44)	-73 (-207-3)	-107 (-297-(-7)	15 (-71-58)
Nickel	65 (56-71)	68 (59-74)	79 (74-83)	75 (69-79)	69 (56-78)	98 (97-99)
Silver	76 (62-85)	70 (51-81)	78 (63-87)	70 (53-80)	74 (46-88)	91 (85-94)

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*From Reference 30.

NOTE: Values represent geometric mean percentage removal and 95 percent CI for the mean (brackets).

Table 27

CUMULATIVE PERCENTAGE REMOVALS FOR ORGANIC PRIORITY POLLUTANTS[†]

Pollutant	Influent Concentration (µg/L)	Lime	Air Stripping	Filtration	Chlorination	Reverse Osmosis
1,1,1-Trichloroethane	4.8	26 (-3 to 46)	96 (95 to 97)	96 (94 to 98)	96 (94 to 98)	99 (98 to 99.4)
Trichloroethylene	1.1	19 (13 to 42)	97 (91 to 99)	96 (80 to 99)	94 (82 to 98)	99 (95 to 99.8)
Tetrachloroethylene	3.6	21 (-12 to 44)	96 (95 to 97)	96 (95 to 97)	80 (73 to 86)	98 (97.5 to 98.9)
Chlorobenzene	0.13	-15 (-70 to 22)	15 (-20 to 41)	0 (-37 to 27)	46 (23 to 62)	46 (23 to 62)
1,3-Dichlorobenzene	0.25	28 (6 to 45)	88 (82 to 92)	88 (81 to 92)	96 (88 to 99)	96 (94 to 97)
1,4-Dichlorobenzene	1.9	28 (15 to 39)	90 (88 to 92)	93 (91 to 94)	98 (98 to 98.5)	99 (98.6 to 99.2)
1,2-Dichlorobenzene	0.74	22 (-8 to 43)	84 (76 to 89)	88 (81 to 92)	93 (89 to 96)	96 (94 to 97)
1,2,4-Trichlorobenzene	0.31	23 (-10 to 46)	61 (45 to 73)	81 (71 to 87)	97 (90 to 99)	97 (94 to 98)
Napthalene	0.11	-36 (-153 to 27)	-73 (-175 to -8)	-18 (-96 to 29)	72 (51 to 85)	45 (19 to 63)
Di-n-butyl Phthalate	0.94	78 (47 to 91)	81 (56 to 91)	NQ	NQ	NQ
Lindane*	0.11	91 (42 to 99)	45 (30 to 57)	NQ	NQ	NQ

[†] From Reference 30.

NQ = Concentrations too low for removals to be quantified.

NOTE: Values represent geometric mean percentage removal and 95 percent CI for the mean (brackets).

Table 28

CUMULATIVE REMOVAL EFFICIENCY FOR SELECTED NONPRIORITY ORGANIC POLLUTANTS†

Pollutant	Percentage Removals* Lime Effluent	Air Stripping Effluent	Filtration Effluent	Granular Activated Carbon Effluent	Chlorination Effluent	Reverse Osmosis Effluent
Tributylphosphate	28 (-70 to 70)	39 (-41 to 75)	70 (-6 to 92)	97 (78 to 99.6)	95 (84 to 99)	93 (83 to 97)
Caffeine	48 (-81 to 85)	51 (-50 to 84)	44 (-78 to 82)	99.9 (76 to 100)	97.2 (11 to 99.9)	95.8 (87 to 98.6)
Lauric Acid	62 (-27 to 89)	25 (-94 to 71)	51 (-38 to 83)	92 (58 to 99)	73 (41 to 88)	91 (69 to 97)
3-Hydroxy-Lauric Acid	82 (-17 to 97)	57 (-66 to 89)	-15 (-380 to 73)	91 (64 to 98)	91 (70 to 97)	82 ?
Myristic Acid	28 (-80 to 71)	18 (-90 to 65)	28 (-47 to 65)	42 (-21 to 73)	44 (4 to 67)	57 (17 to 77)
Palmitic Acid	59 (-4 to 84)	46 (-38 to 79)	55 (8 to 78)	33 (-45 to 69)	56 (16 to 77)	64 (23 to 83)
Stearic Acid	72 (31 to 89)	61 (3 to 85)	71 (43 to 85)	66 (12 to 87)	62 (33 to 79)	78 (53 to 90)
Clofibric Acid	20 (-74 to 64)	38 (-46 to 74)	36 (-88 to 78)	94 (1 to 99)	>99.9 ?	99.9 (92 to 100)
PEGAPE4	16 (-1200 to 95)	26 (-161 to 79)	43 (-223 to 90)	96 ?	96 ?	98 (88 to 99.6)
X11	23 (-134 to 75)	27 (-93 to 73)	55 (-56 to 87)	97 (84 to 99.5)	99.7 (96 to 99.9)	98.6 (22 to 99.9)
X19	48 (-67 to 48)	43 (-57 to 80)	77 (4 to 94)	99.5 (81 to 99.9)	98 (92 to 99)	98.9 (95 to 99.8)
X22	14 (-325 to 83)	33 (-165 to 83)	-17 (-360 to 70)	99 (66 to 99.9)	98.8 (89 to 99.9)	97.6 (89 to 99.5)
117A	51 (-37 to 82)	2 (-136 to 59)	-20 (-180 to 49)	98 (85 to 99.8)	99.9 (98.9 to 100)	99.5 (97.6 to 99.9)
117F	-27 (-265 to 56)	-13 (-233 to 62)	40 (-69 to 79)	91 (61 to 98)	99.7 (92 to 99.9)	99.9 (95 to 100)

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†From Reference 30.

*Values represent geometric mean percentage removal and 95 percent CI for the mean (brackets); ? means 95 percent CI could not be determined.

Chapter 5. SOIL CAPACITY FOR REMOVAL OF CONTAMINANTS

At the outset of this investigation, an assumption was made that if soils would reliably remove certain contaminants from waste water, the soil could be considered part of the treatment process in reclaiming the water. Theoretically then, treatment costs might be minimized and the economic feasibility of a project enhanced.

Central to this concept are two questions:

° What constituents will soils remove?

° How reliable is the process?

The following discussion is directed at answering these questions. Data from previous and existing ground water recharge projects were reviewed to determine soil capacity for removal of various contaminants.

Viruses

Adsorption is the primary mechanism of virus removal by soils /71/. Soils are generally very efficient in retaining viruses, and this effect is well documented. Drewry and Eliassen, for instance, reported removals greater than 99 percent in water percolated through soils from a number of locations in California /72/. In the Chino Basin Water Reclamation Study, discussed in Chapter 2, virus removal was very effective.

Gerba and Lance found that, although adsorption immobilizes viruses, the adsorbing soil particles tend to protect the virus against inactivation. Further, these researchers observed that adsorbed viruses may not always be permanently immobilized, but may elute with rainfall and migrate deeper into the soil column, where they readsorb. Proper management of the recharge system would, however, enable viruses to remain immobilized long enough to become inactivated. Given proper soil type and correct management practices, they felt soil removals of viruses could be sufficiently effective to be used as a part of the treatment process /73/.

Other Microorganisms

Bacteria and other pathogens would be removed efficiently through soil contact. Extensive documentation demonstrates the phenomenon. An example is Aulenbach et al, who reported greater than 99 percent removal of coliforms in 10 feet of sand /21/. Table 29 presents coliform removal data generated in the Hemet-San Jacinto project. These data demonstrate that water taken from the 8 foot depth in the recharge area had only 120 MPN per 100 mL coliforms, as opposed to a 250,000 MPN/100 mL coliform count at the soil surface. The decline in chemical oxygen demand (COD) from 50 to 16 mg/L is further evidence that microorganisms and other oxidizable matter decrease with recharge depth.

Inorganic Contaminants

The effects of soil contact on removal of inorganic contaminants are discussed below.

Nitrates

Sampling data from the Hemet-San Jacinto ground water project, presented in Table 29, indicate nitrates are not removed by the soil, but instead, increase with depth. Findings of the Flushing Meadows Project, discussed in Chapter 2, agree. Decreasing concentrations of organic nitrogen, ammonia, and nitrates indicated increased nitrate concentrations were a result of oxidation of the other nitrogen forms.

Table 29

EFFECTS OF PERCOLATION ON EFFLUENT CHARACTERISTICS
AT THE HEMET-SAN JACINTO GROUND WATER RECHARGE PROJECT*

Constituent	Depth-Feet				
	0	2	4	6	8
Coliform (MPN per 100 mL)	250 000	1 000	1 000	180	120
COD (mg/L)	50	20	17	17	16
NO_3-N (mg/L)	13	29	28	25	30

*From Reference 26.

Sodium

The Flushing Meadows Project demonstrated that concentrations of sodium were the same in the recharged water as in the effluent. Although the Flushing Meadows data do not demonstrate it, soils could affect sodium concentrations through the ion exchange phenomenon. While ion exchange could result in short-term sodium removal, over the long term, the exchange capacity of the soil would become exhausted and sodium would break through. The soils would, therefore, not be a reliable process for sodium removal.

Trace Metals

The Flushing Meadows Project demonstrated reductions of copper and zinc concentrations up to 80 percent as a result of percolating the water through the soil. Lead and cadmium were not affected. Findings of the Hollister study (discussed in Chapter 2) agreed; lead and cadmium were not removed. Also, the latter study found much higher concentrations of manganese in the shallow aquifer than in the waste water effluent, indicating solubilization of soil manganese by the effluent.

To summarize the experience with trace metals, some, such as copper and zinc, may be reduced as a result of soil contact. Others, such as lead and cadmium, are not. Further, there is evidence that waste water affects the chemistry of the soil. Because trace metals are conservative, meaning that they are not destroyed by the soil, the adsorption capacity of the soil could be expected to become exhausted over a period of time so that the soil would no longer remove metals. Therefore, over the long term, the soil would not be reliable as a treatment method for removing metals.

Trace Organics

The Santa Clara Valley Water District recharge project in Palo Alto was discussed in Chapter 2. By using a system of injection and extraction wells, Roberts, et al, evaluated changes in the quality of injected water as it moved through the adjacent soils. The aquifer soils were observed to greatly retard the movement of some organic compounds. Other compounds moved rapidly from the point of injection to extraction /34,35/. Water from an extraction well located 25 feet from the point of injection was analyzed for chloroform and chlorobenzenes. Injected water was detected at the extraction site by means of electrical conductivity measurements. These measurements indicated the injected water traveled to the extraction well within about 11 hours. Chloroform and chlorobenzene concentrations in the extracted water began rising within 50 hours, indicating breakthrough of these compounds. However, 1,3-dichlorobenzene and 1,4-dichlorobenzene had not arrived at the extraction site after over 500 hours of operation /74/.

Once in the aquifer, some organic compounds may rapidly degrade; other compounds may degrade very slowly. Analyses of well samples from the Palo Alto project indicated bromomethanes degraded within 150 days, but concentrations of 1,1,1-trichloroethane, trichloroethylenes, and tetrachloroethylene did not diminish appreciably even after 350 days residence time in the aquifer /75/.

Results of the Phoenix 23rd Avenue Project, presented in Chapter 2, confirm that certain organic compounds are capable of infiltering the soil column and, once in the ground water, are capable of persisting.

Summary

Soils can be extremely effective and reliable in removing virus and bacteria. Nitrates are not removed by soils, and sodium may or may not be, depending upon whether ion exchange occurs. Even if sodium is removed, reliability is a problem, because the exchange capacity of the soil can become exhausted.

Some metals, such as copper and zinc, are removed by soils; some, such as cadmium and lead, are not. Even where metals are removed, reliability is a problem because the adsorption capacity of the soil is limited.

Some organic contaminants, such as dichlorobenzenes, can be removed or effectively retarded by soils, whereas other compounds, such as chloroform, are quite mobile. Soil capacity for organic contaminant removal would be subject to the same reliability problem as for metals, in that the soil has a limited adsorption capacity for compounds that do not degrade.

Based upon the information presented, soils are not effective or reliable enough in removing trace metals and trace organics to be used as part of a treatment process to produce water of drinking quality. There is no doubt that soils provide beneficial treatment. However, for reasons of safety, any benefits realized as a result of soil action will have to be considered incidental.

Chapter 6. CURRENT CONDITIONS IN SANTA CLARA VALLEY

This chapter describes conditions of quality and quantity of water and waste water and their applicability to ground water recharge in Santa Clara County. The information presented will be used as a basis for establishing quality objectives for water to be recharged.

Estimate of the Quality and Quantity of Waste Water Available

If a large-scale waste water reclamation project is implemented, the primary source of reclaimed water will be the San Jose-Santa Clara Water Pollution Control Plant. The estimated quality and quantity of available waste water is based upon flow and quality data from this plant.

The San Jose-Santa Clara Water Pollution Control Plant provides treatment for an average annual flow of 90 mgd. The plant is designed to provide an overall biochemical oxygen demand (BOD) and suspended solids removal of 95 percent. This is accomplished through primary, secondary, and tertiary treatment. The tertiary treatment, including nitrification and filtration, is necessary to adequately treat high BOD and suspended solids loadings associated with food canning activities in the Valley. Characteristics of the waste water and treatment processes found at the San Jose-Santa Clara plant are more fully discussed in the Santa Clara Valley Water Reuse Study, Phase IA, report by the Department of Water Resources /76/. Table 30 presents water quality characteristics of the effluent from the plant, as measured on two occasions. While these data are indicative of the quality of the effluent, the amount of data available is insufficient to characterize the variability in effluent quality.

Table 30

TYPICAL EFFLUENT CHARACTERISTICS OF
SAN JOSE-SANTA CLARA
WATER POLLUTION CONTROL PLANT*

Metals (mg/L)	September 1980	February 1981
Silver	0.002	0.002
Cadmium	0.002	0.002
Chromium	0.006	0.006
Copper	0.015	0.018
Nickel	0.029	0.032
Lead	0.016	0.015
Zinc	0.039	0.044
Arsenic	0.0005	0.002
Cyanide**	0.1	0.1
Mercury	0.00002	0.0002
Fluoride**	1.0	2.7
Constituent (mg/L)		
BOD	2.9	2
Suspended Solids	1.38	0.8
Ammonia	0.103	<0.3
DO	5.2	6.2
Turbidity+	1	0.9
Color+	15	15
Organic-N	1.525	1.45
Nitrite-N	0.008	0.006
Nitrate-N	10.1	18.3
Total Phosphate	14.9	12.4
Specific Conductance++	1 500	1 700
Organics (ng/L)		
Aldrin	<0.04	<0.04
Arochlor 1242	<0.10	<0.10
Arochlor 1260	<0.10	<0.10
BHC	<0.02	<0.02
Chlordane	<0.10	<0.10
Dieldrin	<0.07	<0.07
DDD	<0.09	<0.09
DDE	<0.05	<0.05
DDT	<0.10	<0.10
Endrin	<0.07	<0.07
Heptachlor	<0.04	<0.04
Heptachlor Epoxide	<0.10	<0.10
Lindane	<0.02	<0.02
Methoxychlor	<0.10	<0.10
Toxaphene	NA	NA
Total Identifiable Chlorinated Hydrocarbons (TICH)	<1.0	<1.0
Average Total Coliform† (MPN/100mL)	24.7	16

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*From Reference 77.
**24-hour composite sample.
+Value in units.
++Station C-1 values in microsiemens (μS).
†7-day sample median.

Waste Water Blending

The quantity and quality of imported and local waters that could be used for waste water blending in the study area were based on estimates by the following sources:

- ° Anderson Reservoir Limnologic Investigation, by the California Department of Water Resources and the Santa Clara Valley Water District, May 1978 /79/.
- ° State Water Project, Report of Operations, December 1980 /80/.
- ° Water Action Plan Central and South San Francisco Bay Area, October 1982 /81/.

Imported Water

The primary source of imported water for Santa Clara County is the South Bay Aqueduct. In 1977-78, 80,000 acre-feet of water was delivered to Santa Clara County. Of this, 43,000 acre-feet was treated at the Rinconada Water Treatment Plant and 17,000 acre-feet was treated at the Penitencia Water Treatment Plant for delivery to consumers through retail water agencies. An additional 800 acre-feet of raw water was delivered directly for use by individual contractors from pipelines of the Santa Clara Valley Water District. The remaining 19,000 acre-feet was recharged into the underground water supply through Santa Clara Valley Water District's recharge facilities /76/. Quality data for South Bay Aqueduct water are presented in Table 31.

Table 31

WATER QUALITY AT SOUTH BAY AQUEDUCT TERMINAL RESERVOIR - 1980†

Constituents	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual Average
*Total Dissolved Solids	240	230	181	175	161	174	162	143	200	186	170	175	183
*Total Hardness	89	86	78	76	70	75	70	62	86	80	73	76	77
*Chlorides	39	37	35	33	29	33	29	24	40	36	32	33	33
*Sulfates	36	34	28	27	25	27	25	22	31	29	26	27	28
*Sodium	32	31	29	28	25	27	25	21	32	29	26	27	28
Percent Sodium	44	44	44	44	44	44	44	43	45	44	44	44	44
*Specific Conductance	349	333	308	297	271	294	272	237	343	316	286	297	300
Specific Conductance	367	422	328	307	231	295	251	206	354	311	292	296	305
pH	8.6	8.4	8.0	7.2	8.0	7.7	7.6	7.7	8.3	8.9	7.6	7.4	8.2
Boron	0.2	0.1	0.2	0.2	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1
Fluoride	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Lead	0.01	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.01	0.01
Selenium	0.02	0.00	0.00	0.01	0.01	0.03	0.00	0.00	0.02	0.00	0.02	0.01	0.01
Hexavalent Chromium		0.00							0.00				0.00
Arsenic	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Iron	0.03	0.02	0.01	0.01	0.01	0.01	0.00	0.00	0.01	0.00	0.00	0.03	0.01
Manganese	0.00	0.01	0.01	0.02	0.01	0.01	0.01	0.02	0.02	0.01	0.01	0.01	0.01
Magnesium	10	19	15	9	5	8	7	7	13	12	8	9	10
Copper	0.03	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.02	0.01
Calcium	20	33	27	18	11	16	14	12	24	22	16	17	19
Zinc	0.05	0.02	0.01	0.02	0.02	0.00	0.01	0.01	0.02	0.00	0.01	0.02	0.02
Phenol		0.000							0.000				0.000
Color	20	10	18	12	12	15	20	10	10	15	10	25	15
Sampling Date	01/15	02/19	03/18	04/15	05/20	06/17	07/15	08/19	09/16	10/14	11/18	12/16	

† From Reference 79.
* Flow weighted values correlated from continuous EC.

Water is also imported to the Santa Clara Valley from San Francisco Water Department's Hetch Hetchy Aqueduct. This water is supplied directly to the cities that contract for it and will not be considered in this report.

San Felipe Project

The U. S. Bureau of Reclamation is constructing a water delivery system to supply Santa Clara County, San Benito County, and possibly Santa Cruz and Monterey Counties. Water for the project will be diverted from the Sacramento-San Joaquin Valley to San Luis Reservoir. A tunnel in the Pacheco Pass vicinity will be used to convey the water into Santa Clara Valley. Deliveries from the project are scheduled to begin in 1988. Table 32 indicates annual amounts of San Felipe water that are to be provided to Santa Clara Valley Water District.

Local Surface Water

Santa Clara Valley Water District operates eight dams and reservoirs with a total capacity of 155,000 acre-feet. This water is released for ground water recharge and direct surface irrigation. One of the major reservoirs in the system is Anderson Reservoir, near Morgan Hill. The quality of Anderson Reservoir water is summarized in Table 33. Table 34 shows the storage capacities of all Santa Clara County reservoirs. Local surface water supplies have been discussed more extensively in the Santa Clara Valley Water Reuse Study, Phase IA, report, published in December 1980 /76/.

Table 32

SANTA CLARA VALLEY WATER DISTRICT
SAN FELIPE PROJECT MINIMUM ANNUAL DELIVERIES*

Year	Minimum Water Delivery	Minimum M&I Water Delivery
1	16,000	16,000
2	22,000	20,000
3	27,000	24,000
4	32,000	28,000
5	37,000	32,000
6	43,000	36,000
7	49,000	40,000
8	55,000	44,000
9	61,000	48,000
10	67,000	52,000
11	74,000	56,000
12	79,300	58,300
13	84,600	60,600
14	89,900	62,900
15	95,200	65,200
16	100,600	67,500
17	102,900	69,800
18	105,200	72,100
19	107,500	74,400
20	109,800	76,700
21	112,100	79,000
22	114,400	81,300
23	116,700	83,600
24	119,000	85,900
25	121,300	88,200
26	123,600	90,500
27	125,900	92,800
28	128,200	95,100
29	130,500	97,400
30	132,800	99,700
31	135,100	102,000
32	137,100	104,000
33	139,100	106,000
34	141,100	108,000
35	143,100	110,000
36	145,100	112,000
37	147,100	114,000
38	149,100	116,000
39	151,100	118,000
40	152,500	119,400

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*Contract between the U. S. Department of the Interior, Bureau of Reclamation, and Santa Clara Valley Water District. /81/ Annual deliveries in the contract are in acre-feet.

Table 33

ANALYSES OF SURFACE WATER
ANDERSON RESERVOIR*
(April 9, 1975, Depth 10 metres)

Constituent	Concentration+
Dissolved Oxygen	9.9
Electrical Conductivity	350 μS
pH	8.2
Calcium†	36
Magnesium	14
Sodium	16
Potassium	1.9
Bicarbonate	157
Carbonate	0
Sulfate	36
Chloride	9.7
Boron	0.1
NO_3-N	0.07
NH_3-N	0.03
Org-N	0.3
Ortho-P	0.01
Total Phosphorus	0.02
Turbidity	2 NTU
Copper	0.01
Iron	0.03
Manganese	0
Zinc	0.15
TDS	211
Total Hardness†	148
Sodium	19%

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*From Reference 78.
+Units are milligrams per litre unless noted.
†As $CaCO_3$.

Table 34

RESERVOIR STORAGE*

Reservoir	Capacity (ac-ft)
Almaden	1,800
Anderson	91,300
Calero	10,200
Chesbro+	8,100
Coyote	23,700
Guadalupe	3,700
Lexington	20,200
Pacheco†	6,100
Stevens Creek	3,600
Uvas+	10,000
Vasona	400

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*From Reference 82.
+South Santa Clara Valley Water Conservation District's reservoirs.
†Pacheco Pass Water District reservoir.

Amount and Quality of Underlying Ground Water

The ground water storage capacity and the existing ground water quality in the Santa Clara Valley have been estimated.

Amount

Ground water is the source of more than half the water used in Santa Clara Valley, where there are three main ground water subbasins:

- Llagas subbasin, from Gilroy north of Morgan Hill.
- Coyote subbasin, from north of Morgan Hill to Coyote.
- North Santa Clara subbasin, from Coyote north to Palo Alto and Milpitas.

Yield from the three subbasins is between 230,000 and 250,000 acre-feet of water each year.

North Santa Clara Valley ground water subbasin can store an estimated 3 million acre-feet between the 9 and 285 foot depth levels. This, however, is the gross theoretical storage capacity. The portion of this capacity that can actually be considered as usable storage capacity has not been determined.

The primary purpose of the water retained in Santa Clara Valley Water District reservoirs is to replenish the ground water basin. Reservoir releases are made to maximize the total amount of water recharged. Whenever practical, recreational pools are maintained during the summer. The areas of ground water deficiency are a first priority for recharge. A list of the percolation pond facilities, with the maximum theoretical recharge rate, is shown in Table 35. Those recharge facilities that are a part of a park complex or leased to other agencies for recreation are kept filled as much as possible.

PERCOLATION FACILITIES IN SANTA CLARA COUNTY*

Name	Ponds	Surface Area (ac)	Maximum Recharge Rate (ac-ft/ac/day)	Source of Water
Alamitos	2	15	1	Local and Imported
Budd	3	9	3	Local and Imported
Camden	3	62	0.5	Local and Imported
Coyote	1	30	2	Local
Ford Road	4	34	1	Local
Guadalupe	4	48	0.5	Local
Kooser	4	2	5	Imported
Los Capitancillos	9	63	0.5	Local and Imported
Main Avenue	5	6	2	Local
McClellan	1	2.5	2	Imported
McGlincey	6	7	7	Local and Imported
Oka	4	17	1	Local and Imported
Overfelt Gardens	4	--	--	Local and Imported
Page	8	14	2	Local and Imported
Penitencia	5	14	1	Local and Imported
Sunnyoaks	4	3	3	Local and Imported

---

*From Reference 83.

Quality

Ground water quality varies with depth and location. Within the Santa Clara Valley subbasin are three ground water zones:

- A semiperched water body overlying the confined zone.
- A main, confined, water-bearing zone.
- A main, unconfined, water-bearing zone, which is the principal source of recharge to the confined zone.

Irrigation wells in north Santa Clara County have a maximum depth of 1,100 feet, and average 400 feet. The quality of water taken from these wells depends on the depth of the well and on whether water is taken from one or more ground water zones. In general, the ground water meets or exceeds all drinking water standards of the U. S. Public Health Service. The pumped water may be classified as moderately to extremely hard.

Certain localized areas have yielded ground water of poor quality as a result of contamination from tidal waters or degradation from subsurface sources. For example, studies indicate that the upper aquifer (less than 150 feet deep) fringing San Francisco Bay is widely intruded by sea water. In 1977, a sampling of 103 wells in north Santa Clara Valley, where intrusion was not significant, gave the average values for mineral constituents shown in Table 36.

Table 36

GROUND WATER QUALITY-NORTH SANTA CLARA VALLEY†

Township/ Range	Number of Wells Sampled	TDS*	Hardness+	Ca	Mg	Na	HCO_3	EC
6S/1E	13	473	219	51	21	96	317	808
7S/1E	40	412	312	63	37	33	322	701
7S/1W	36	284	209	52	19	20	198	485
8S/1E	14	322	269	51	34	19	238	576
Wt. Ave.	103	364	258	56	28	35	267	622

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† From Reference 77.

* Units = mg/L, except EC = µS.

+ As $CaCO_3$.

Chapter 7. RECLAMATION PROJECT ALTERNATIVES

Three alternatives examined for recharging Santa Clara Valley ground water with reclaimed water are discussed in this chapter. Under all three alternatives, waste water would be collected from the San Jose-Santa Clara Water Pollution Control Plant and provided with additional treatment as necessary. Water recharged by any of the alternatives could be used for all purposes for which the existing supply is used. These include agricultural, industrial, and domestic uses.

Under Alternative A, surface spreading, the reclaimed water would be conveyed about 28 miles to the southeast portion of the North Valley ground water subbasin. Percolation ponds would be used to recharge the reclaimed water by surface spreading.

Under Alternative B, shallow aquifer restoration, the water would be conveyed a short distance and injected into the semiperched ground water aquifer overlying the deeper drinking water aquifer of the Santa Clara Valley basin. The semiperched aquifer is presently saline as a result of intrusion from San Francisco Bay. This project would renovate the aquifer for beneficial uses through a process of injection of reclaimed water and extraction of saline water. Once the salinity of the water in the aquifer had fallen to acceptable levels, the water could be pumped and used. Treatment requirements might vary depending upon the uses to which the water would be put.

Under Alternative C, deep injection, the reclaimed water would be conveyed to an area near the treatment plant and injected into the main (drinking water) aquifer of the North Santa Clara subbasin.

Evaluation of Project Alternatives

The following is an evaluation of the alternatives studied and a determination of the best apparent alternative.

Alternative A
Surface Spreading

As ground water recharge by surface spreading is accomplished using the force of gravity, no energy input is needed to get recharge water into the aquifer. This is a major advantage over direct injection. The least expensive means of recharging a ground water aquifer would usually be to apply the water to the ground surface at a point near the source of the recharge water. By this approach, energy costs for water conveyance would be minimized and, of course, getting the water into the ground would, by itself, cost nothing. Project costs would primarily involve providing additional treatment as required, providing conveyance to the point of recharge, purchasing land for spreading basins, and operating and maintaining the system. Also, as the unsaturated soil zone has a demonstrated capacity for removing some pollutants, treatment requirements might be less than for recharge through direct injection into a saturated soil zone.

These were the concepts underlying original consideration of Alternative A. Subsequent study indicated problems with these concepts.

Chapter 5 included a discussion of the capacity of soils to remove water contaminants. Some pollutants are degraded in an aquifer, and some are greatly retarded in their movement.

However, some pollutants do not degrade readily and some are quite mobile within the aquifer. Based on these findings, the conclusion was that when treating water to be used for potable purposes, the soils should not be relied upon as part of the treatment chain. The interaction of reclaimed water with soils should, in most cases, have a beneficial effect on the reclaimed water, but the lack of reliability is such that any benefits will have to be considered incidental. This conclusion has important implications for the study. Water treatment requirements for surface spreading into a drinking water aquifer would have to be the same as if the water were directly injected into the aquifer. Therefore, surface spreading will have no advantage in reduced treatment costs, even though surface spreading might improve treatment reliability.

Water Quality Objectives. For reclaimed water to be safe for drinking, it would need to meet all applicable drinking water standards. In addition, assurance would be needed that concentrations of toxic agents would be reduced to below levels that would be expected to cause adverse effects. Table 37 lists California Interim Primary and Secondary Drinking Water Standards. These requirements would apply. (The Interim Criteria are being revised, and some of the criteria may change.)

Table 37

DOMESTIC WATER QUALITY CRITERIA[+]

California Primary Drinking Water Standards

Physical Character

Constituent	Maximum Contaminant Level
Turbidity	0.5 T.U. (mo. avg.)

Bacteriological Character

Constituent	
Coliforms	1 per 100 mL (arithmetic mean/mo.)

Inorganic Chemicals

Constituent	Maximum Contaminant Level, mg/L
Arsenic	0.05
Barium	1
Cadmium	0.010
Chromium	0.05
Fluoride	1.8*
Lead	0.05
Mercury	0.002
Nitrate (as NO_3)	45
Selenium	0.01
Silver	0.05

Organic Chemicals

(a) Chlorinated Hydrocarbons:	
Endrin	0.002
Lindane	0.004
Methoxychlor	0.1
Toxaphene	0.005
(b) Chlorophenoxys:	
2,4-D	0.1
2,4,5-TP Silvex	0.01
(c) Trihalomethanes	0.1

Radiological Character

Constituent	Maximum Contaminant Level, pCi/L
Combined Radium-226 and Radium-228	5
Gross Alpha particle activity (including Radium-226 but excluding Radon and Uranium)	15
Tritium	20 000
Strontium-90	8
Gross Beta particle activity	50

California Secondary Drinking Water Standards

Constituent	Maximum Contaminant Level
Color	15 Units
Copper	1.0 mg/L
Corrosivity	Relatively low
Iron	0.3 mg/L
Manganese	0.05 mg/L
Odor-Threshold	3 Units
Forming Agents (MBAS)	0.5 mg/L
Turbidity	5 Units
Zinc	5.0 mg/L

Mineralization-Secondary Drinking Water Standards

Constituent, Units	Recommended Maximum Contaminant Level
Total Dissolved Solids, mg/L, or	500
Specific Conductance, Microsiemens per centimetre (µS/cm)	900
Chloride, mg/L	250
Sulfate, mg/L	250

[+] From Reference 84.

*Maximum Contaminant Level of fluoride when annual average maximum daily air temperature is between 17.7 and 21.4 degrees Celsius.

Besides these criteria, there would probably be a requirement for reduction in levels of other hazardous compounds found in reclaimed waste waters. The California requirements apply to raw water with little waste water contamination. Standards are not available to judge the safety of reclaimed waters. However, the Environmental Protection Agency has developed water quality guidelines for toxic pollutants. These guidelines, summarized in Table 38, might be used to help judge the suitability of more contaminated sources. These criteria were not intended as drinking water standards and should, therefore, be used only as preliminary guidelines. The toxic pollutants criteria are subject to change as additional health effects research is completed.

Specific health criteria for this reclamation project would be developed by the California Department of Health Services on a case-by-case basis. However, for the purposes of this feasibility study, the assumption will be made that the criteria appearing in Tables 37 and 38 would apply.

Recommended Treatment and Estimated Treatment Cost. In addition to the treatment already provided by the San Jose-Santa Clara Water Pollution Control Plant, the water to be recharged under Alternative A would probably require activated carbon treatment and reverse osmosis to meet more stringent water quality criteria. The reverse osmosis system would likely be patterned after that of Water Factory 21. That system has a decarbonator that provides aeration. Therefore, the benefits of air stripping for volatile organics removal are included with reverse osmosis. These processes, which are discussed in Chapter 4, will produce a water meeting all established drinking water standards and should meet standards likely to be adopted for reclaiming waste water for indirect potable use. It is anticipated that treatment processes resulting in substantial reductions of a wide range of materials will be capable of reducing other contaminants that may be present but cannot now be identified.

The estimated cost for this treatment, including associated costs of pumping and disinfection, ranges from \$350 to \$420 per acre-foot of water treated, based on the experience of Water Factory 21 /86/. This estimate reflects full amortization of capital costs, plus operations and maintenance costs. The basis for the cost estimates is more fully discussed at the end of this chapter, and is summarized in Table 39.

An alternative for producing recharge water of acceptable mineral quality would be to blend the reclaimed water with fresh water. Based on the average quality of imported water that might be available for blending, a blend ratio of one part reclaimed to two parts fresh water would be required to achieve adequate salinity reduction. If the cost of blending water were assumed to be between \$245 and \$670 (1981 dollars) per acre-foot, blended water would cost between \$200 and \$490 per acre-foot. This estimate assumes the water to be pumped would be from an as yet undeveloped supply of the State Water Project. (The cost of future water supplies is discussed later in this chapter.) However, other options may be available. If a water supply costing less were used for blending, the cost of blended water could be significantly reduced. This approach might be attractive to a local agency that would be able to employ blending to augment the existing water supply.

Although the cost of blending might be competitive with the cost for reverse osmosis, blending was rejected in this study. The additional advantage of reverse osmosis is that it would remove toxic contaminants present in the reclaimed water. This additional margin of safety would be necessary to adequately protect public health.

There is a major problem in the concept of recharging reclaimed water into the Santa Clara Valley ground water basin through surface spreading. The portion of the basin in the area of the San Jose-Santa Clara Water Pollution Control Plant is a pressure zone. That is, an impervious layer overlies the drinking water aquifer in that area. Therefore, water cannot be percolated into the potable aquifer. To avoid the confining layer, the recharge project would have to be located in the southern portion of the aquifer, near the recharge facilities of the Santa Clara Valley Water District (these were discussed in Chapter 6).

Conveying the water to the recharge area would be expensive. Based on cost estimates performed in Phase IA of this study, the estimated conveyance cost would be $375 per acre-foot. This figure is based on an assumed project capacity of 8,000 acre-feet per year.

Another problem would be locating spreading areas. As Santa Clara Valley Water District fully uses its existing recharge facilities, new areas would presumably have to be developed. Based on an assumed maximum recharge rate of 1 acre-foot per acre per day, an 8,000 acre-feet per year recharge capacity would require about 330 acres of spreading area. These estimates are based on actual recharge data from Santa Clara Valley Water District, appearing in Chapter 6. The cost of the land would vary, depending on location, but land cost would be a major cost component of the project.

The estimated cost for providing the necessary treatment and conveyance would amount to between $720 and $800 per acre-foot not including major costs for spreading grounds. As this cost would be far in excess of the cost of alternative water supplies, Alternative A would be economically infeasible.

Alternative B
Shallow Aquifer Restoration

Historically, water from the semiperched zone was used for agricultural irrigation. However, salt water intrusion from San Francisco Bay eventually turned the aquifer saline, and beneficial uses of the aquifer ceased. The concept of renovating the aquifer is an attractive one, in that presently unusable water storage capacity would be rendered usable. Then, water from this shallow aquifer could be withdrawn and used for agricultural irrigation or industrial or domestic water supply in the area. The shallow depth of the water would make pumping relatively inexpensive, and the aquifer could be used as a distribution system, making overland piping unnecessary and thus saving capital costs.

To renovate the aquifer, a system of injection and extraction wells would be needed. Injection wells would be used to build a hydraulic mound that would prevent further salt water intrusion; extraction wells positioned on the landward side of the mound would extract saline water from behind the barrier. Extracted water would be disposed of to the bay.

After a time, the aquifer would be purged of saline water. Then extraction could begin and continue at a rate approaching the injection rate.

While this alternative has some attractive features, it also has some major drawbacks. This concept assumes purging the saline water from the aquifer would be technically and economically feasible. This may not be the case.

Since the time when the water in the perched water zone was successfully used for agriculture, major flood channel improvements have been made to the Guadalupe River. The downstream portion

Table 38

FEDERAL WATER QUALITY CRITERIA FOR TOXIC POLLUTANTS, 1980†

Pollutant	Limit	Pollutant	Limit
Acrolein	320 µg/L	*Acrylonitrile	0.058 µg/L
*Dieldrin	0.071 ng/L	*Aldrin	0.074 ng/L
Antimony	146 µg/L	*Arsenic	2.2 ng/L
*Asbestos	30,000 fibers/L	*Benzene	0.66 µg/L
*Benzidine	0.12 ng/L	*Beryllium	3.7 ng/L
Cadmium	10 µg/L	*Carbon Tetrachloride	0.40 µg/L
*Chlordane	0.46 ng/L	*Hexachlorobenzene	0.72 ng/L
1,2,4,5-tetrachlorobenzene	38 ng/L	Pentachlorobenzene	74 µg/L
*1,2-dichloroethane	0.94 µg/L	Chlorobenzene	488 µg/L
*1,1,2-trichloroethane	0.6 µg/L	1,1,1-trichloroethane	18.4 mg/L
*Hexachloroethane	1.9 µg/L	*1,1,2,2-tetrachloroethane	0.17 µg/L
2,4,5-trichlorophenol	2.6 mg/L	*2,4,6-trichlorophenol	1.2 µg/L
*Bis(chloromethyl)-ether	0.0038 ng/L	*Bis(2-chloroethyl)-ether	0.03 µg/L
Bis(2-chloroisopropyl)-ether	34.7 µg/L	*Chloroform	0.18 µg/L
Chromium VI	0.50 µg/L	Chromium III	170 mg/L
*DDT	0.024 ng/L	Cyanide	200 µg/L
*Dichlorobenzidines	0.0103 µg/L	Dichlorobenzenes	400 µg/L
2,4-dichlorophenol	3.09 mg/L	*1,1-dichloroethylene	0.033 µg/L
*2,4-dinitrotoluene	0.11 µg/L	Dichloropropenes	87 µg/L
Endosulfan	74 µg/L	*1,2-diphenylhydrazine	42 ng/L
Ethylbenzene	1.4 mg/L	Endrin	1 µg/L
*Halomethanes	0.19 µg/L	Fluoranthene	42 µg/L
*Hexachlorobutadiene	0.45 µg/L	*Heptachlor	0.28 ng/L
*Beta-hexachlorocyclohexane	16.3 ng/L	*Alpha-hexachlorocyclohexane	9.2 ng/L
*Gamma-hexachlorocyclohexane	18.6 ng/L	*Tech-hexachlorocyclohexane	12.3 ng/L
Isophorone	5.2 mg/L	Hexachlorocyclopentadiene	206 µg/L
Lead	50 µg/L	Mercury	144 ng/L
Nickel	13.4 µg/L	Nitrobenzene	19.8 mg/L
2,4-dinitro-o-cresol	13.4 µg/L	Dinitrophenol	70 µg/L
*N-nitrosodimethylamine	1.4 ng/L	*N-nitrosodiethylamine	0.8 ng/L
*N-nitrosodi-n-butylamine	6.4 ng/L	*N-nitrosodiphenylamine	4 900 ng/L
*N-nitrosopyrrolidine	16.0 ng/L	Pentachlorophenol	1.01 mg/L
Phenol	3.5 mg/L	Dimethylphthalate	313 mg/L
Diethylphthalate	350 mg/L	Dibutylphthalate	34 mg/L
Di-2-ethylhexylphthalate	15 mg/L	*Polychlorinated biphenyls (PCBs)	0.079 ng/L
*Polynuclear aromatic hydrocarbons	2.8 ng/L	Selenium	10 µg/L
Tetrachloroethylene	.8 µg/L	Silver	50 µg/L
Toluene	14.3 mg/L	Thallium	13 µg/L
*Trichloroethylene	2.7 µg/L	*Toxaphene	0.71 ng/L
2,3,7,8-tetrachlorodibenzo-p-dioxin	$0.21x10^{-9}$ µg/L	*Vinyl chloride	2.0 µg/L

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† From Reference 85.

* Suspected carcinogen. Concentration limit shown is the concentration level that would be expected to cause cancer in one out of one million exposed persons over their lifetimes.

of the stream channel was deepened to the depth of the water-bearing strata. Tidal movement of bay water up the river channel causes saline bay water to come in contact with the porous strata of the aquifer. Movement of saline water into the aquifer is, therefore, probably relatively unimpeded as compared to the historical condition.

Although this problem has not received sufficient study to enable firm conclusions, there is a likelihood the aquifer could not be renovated without somehow preventing saline water from entering the aquifer through the river channel. Alternative means of accomplishing this might include erecting a barrier at the river mouth or sealing the channel. Because flood control is the major purpose of the channel, erecting a barrier would probably be unacceptable, as any structure across the river mouth might inhibit floodflows.

The alternative of sealing the river channel would probably be the most acceptable solution to preventing bay water from entering the aquifer; however, this alternative would be expensive.

Assuming bay water could be excluded from entering the aquifer through the river channel, the next problem would be the actual renovation. Clearly a considerable period would be required to flush salinity from the aquifer. During this period no usable water would be produced, so the cost of the renovation phase of the project would have to be amortized over the production phase of operations. A key question is how much reclaimed water would have to be devoted to renovating the aquifer. There is not yet a clear answer to this question. Data are inadequate to accurately estimate the volume of saline water to be replaced or to enable an understanding of the chemical interactions that would occur in the aquifer. Therefore, the volume of flushing water needed cannot be calculated.

Because of the shallow depth to ground water in this area the recharge facilities would have to be operated carefully to avoid waterlogging the soil and flooding subsurface structures such as basements.

Another problem is that the aquifer is known to be heterogeneous in composition, but the precise makeup of the aquifer is not known. Before a renovation strategy could be defined, much more information about the aquifer would be needed.

Although the amount of water needed to renovate the aquifer cannot now be determined accurately, substantial costs would be involved. Assuming that the aquifer were renovated, the next issue would be to define the nature of the uses to which the water would be put. The area has considerable agricultural development. According to land use projections for the area, 10,000 acre-feet of water will be used on lands surrounding the waste water treatment plant in 1990; agricultural use is expected to drop to 6,500 acre-feet in the year 2000, and to 4,800 acre-feet per year by 2010. The projected decline in agricultural usage is due to expected industrial development in the area. Industrial demand for water in the area is expected to be 13,000 acre-feet in 1990 and 13,700 acre-feet in the year 2000.

If the reclaimed water were restricted to agricultural and industrial uses, the water from the San Jose-Santa Clara Water Pollution Control Plant might not require additional treatment for removal of constituents of health concern. Dissolved minerals and metals would be the primary constituents affecting the uses of the water. The water from the treatment plant has a total dissolved solids concentration of about 900 mg/L, and an adjusted sodium adsorption ratio of 12.5. (This information appears in the Phase IA report.) Salinity concentrations of this magnitude are, in most cases, too high for successful

Table 39

RECLAMATION COST ESTIMATE COMPONENT SUMMARY

	Costs for Unit Process ($/MG)							
Cost Component	Influent Pumping	Carbon Adsorption	Carbon Regeneration	Chlorination	Reverse Osmosis (high pres.)	Reverse Osmosis (low pres.)	Well Injection	Total
Chemicals								
Chlorine ($.117/lb)				21.70	0.80	0.80		
Activated Carbon ($.7057/lb)			24.70					
Sulfuric Acid ($.032/lb)					21.40	21.40		
SHMP ($.4460/lb)					31.20	31.20		
Energy								
Electricity ($.056/kWh)	7.10	30.40	9.10	12.70	477.80	352.80	18.90	
Gas ($1.02/Therm)			32.70		2.10	2.10		
Maintenance								
Materials	2.60	4.80	3.60	5.20			1.80	
Contract					122.40	93.80		
Labor								
Operation	4.10	6.30	17.80	12.20	17.00	15.10	2.40	
Maintenance	4.10	4.20	5.20	6.10			3.20	
Capital	.80	81.30	30.10	18.80	258.20	197.70	3.30	
Totals								
With High Pressure R. O. Membranes ($/ac-ft)	18.70 (6.10)	127.00 (41.40)	123.20 (40.20)	76.70 (25.00)	930.90 (303.38)	-- --	29.60 (9.60)	1,306.10 (425.70)
		(81.60)						
Totals								
With Low Pressure R. O. Membranes ($/ac-ft)	18.70 (6.10)	127.00 (41.40)	123.20 (40.20)	76.70 (25.00)	-- --	714.90 (233.00)	29.60 (9.60	1,090.10 (355.30)
		(81.60)						

agricultural use. Phase IA of this study examined the suitability of the water from the San Jose-Santa Clara plant for agriculture. The conclusion was that a blend of two parts fresh water to one part reclaimed water would be required to achieve a suitable mineral balance. A similar blend would probably be required to reduce the mineral and metal content to a satisfactory level for industrial use.

Water for blending might be pumped from the lower, drinking water aquifer in the area of the treatment plant. If the cost of this water were taken to be that of future State Water Project supplies, blending water might cost between $245 and $670 per acre-foot (1981 dollars). The basis for this estimate is discussed in more detail at the end of this chapter. If a two to one blend would produce acceptable mineral quality, the cost of blended water would be between $200 and $490 per acre-foot, not including costs for recharging.

Reverse osmosis would be an alternative means of reducing the mineral content of the water. The cost of blended water using reverse osmosis would be between $190 and $240 per acre-foot, assuming two- thirds of the water would be subjected to reverse osmosis costing between $230 and $300 per acre-foot, and mixed with the remaining one-third of the water costing $120 per acre-foot. Again, the cost for reverse osmosis is based on the experience of Water Factory 21 (see Table 39).

This analysis has indicated that, without considering solutions to the major problems in renovating the aquifer, there is an apparent possibility of producing suitable industrial and agricultural water at a reasonable price. However, the uncertainties involved with the renovation process are large. A physical solution to sealing the aquifer would be expensive, as would renovating the aquifer once it had been sealed. Based on the limited knowledge available, it seems doubtful this project alternative would be viable. Considerable additional study would be required to enable certainty in this determination.

Alternative C
Deep Injection

Under this alternative, water from the San Jose-Santa Clara Water Pollution Control Plant would be injected into the drinking water aquifer near the plant. Figure 8 depicts an area near the treatment plant where reduced pressures presently exist in the drinking water aquifer. These reduced pressures are caused by a higher pumping rate in this area as compared to the surrounding area. Therefore, this is an area of higher water demand. The proposal would be to locate the injection facilities so as to supply this demand; the water would need to be conveyed only a short distance.

Quality Criteria. For this alternative, the assumption is that the criteria listed in Tables 37 and 38 would apply.

Recommended Treatment and Estimated Treatment Cost. Additional treatment recommended for this alternative is the same as for Alternative A -- activated carbon adsorption and reverse osmosis, including associated pumping and disinfection, at a cost ranging from $350 to $420 per acre-foot. The cost of pumping and of constructing, operating, and maintaining injection facilities would be about $10 per acre-foot, assuming a project capacity of 10,000 acre-feet per year (based on Water Factory 21 experience). The total cost of the water would, therefore, range from $360 to $430 per acre-foot.

Of the alternatives considered, Alternative C, direct injection into the drinking water aquifer appears to have the most promise. An appropriate next step is to compare the estimated cost of this alternative to other water supply alternatives.

Cost Comparison of Reclaimed Versus Fresh Water Supply Alternatives

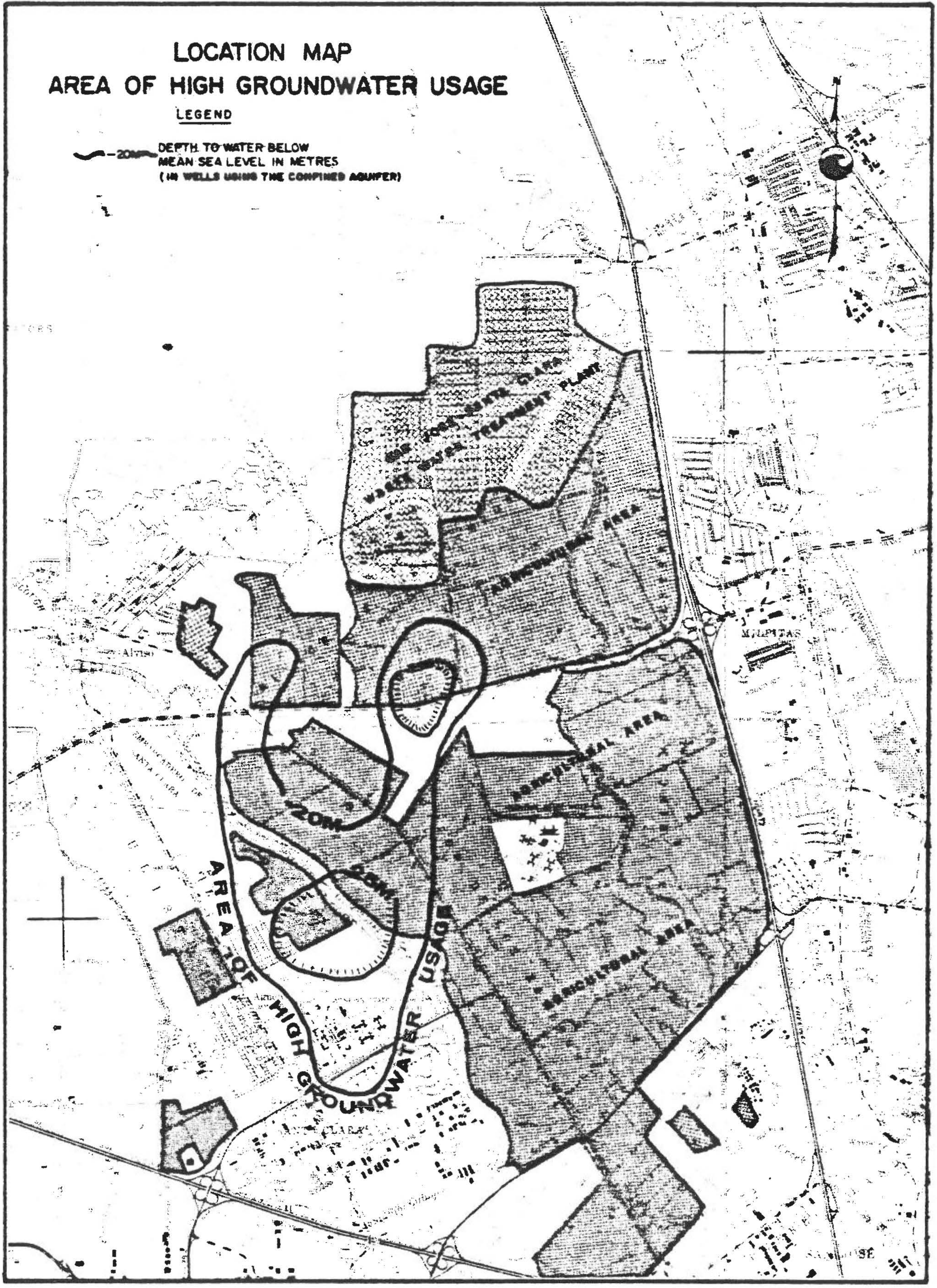
The San Felipe Project, discussed in Chapter 6, will supply the Santa Clara Valley with water for municipal and industrial uses at a cost of $61 per acre-foot /81/. A reclamation project producing water costing between $360 and $430 per acre-foot cannot compete economically with this water supply. There is, however, another perspective.

The State Water Project also supplies the Santa Clara Valley through the South Bay Aqueduct, also discussed in Chapter 6.

Future supplies of the State Water Project will have to come from sources not yet in existence. Department of Water Resources Bulletin 76-81 lists numerous surface water supply alternatives that are receiving consideration. These projects, along with estimated costs of delivering the water to Santa Clara Valley Water District, appear in Table 40.

Additional water supplies delivered to the Santa Clara Valley through the State Water Project would cost from $245 to $670 per acre-foot (1981 dollars), depending on which projects are eventually built. This estimate represents the anticipated incremental costs of new State Water Project water supplies. The reclamation project might

Figure 8


LOCATION MAP
AREA OF HIGH GROUNDWATER USAGE
LEGEND
-20M- DEPTH TO WATER BELOW MEAN SEA LEVEL IN METRES
(IN WELLS USING THE CONFINED AQUIFER)
SAN JOSE-SANTA CLARA
WASTE WATER TREATMENT PLANT
AGRICULTURAL AREA
AGRICULTURAL AREA
AGRICULTURAL AREA
20M
20M
AREA OF HIGH GROUNDWATER USAGE
MILPITAS
Alviso
SANTA CLARA

be economically justified, depending on which fresh water supply projects are considered as alternatives.

If a reclamation project were determined to be economically justified, it could be implemented through the Department's December 1982 "Revised Guidelines for Funding Local Water Supply Projects for Inclusion in the State Water Project".

Economic justification is but one aspect of the overall feasibility of a waste water reclamation project in the Santa Clara Valley. A proposed project to recharge into a drinking water supply would encounter the immediate problem that no water quality standards exist for reclaiming waste water for potable use. These standards would have to be established through the California Department of Health Services. In addition, a proposed project would have to be demonstrated to be safe and accepted by the ultimate consumers of the area.

Basis of Reclamation Cost Evaluation

Fiscal year 1979-80 unit costs for Water Factory 21, in Orange County, were used for cost estimates for the following reclamation steps:

- ° Carbon adsorption
- ° Carbon regeneration
- ° Chlorination
- ° Reverse osmosis (including air stripping)

The unit labor, maintenance material, and capital costs of the first three steps were reduced by 57 percent under the assumption that total costs in these categories would have remained the same if Water Factory 21 had been operated at design capacity (15 mgd) rather than at the 6.5 mgd average experienced during fiscal year 1979-80. All unit costs for the reverse osmosis plant were adjusted using Environmental Protection Agency cost/capacity curves for reverse osmosis plants. Capital costs of the reverse osmosis plant were estimated by applying average capital cost figures supplied by the Oakridge National Laboratory /88/. The following factors were used to adjust the costs for the 5 mgd Water Factory 21 reverse osmosis plant to estimate the costs for the proposed 15 mgd plant:

Cost Category	Factor
Construction	.85
Energy	.96
Maintenance Materials	.87
Labor	.44

After the above adjustments were made, costs were updated to average 1981 cost levels using:

- ° Chemical cost indices computed from data prepared by the Santa Clara Valley Water District.
- ° Intermediate goods indices prepared by the U. S. Bureau of Labor.
- ° Capital and labor cost indices from the Engineering News Record.
- ° Unit natural gas cost computed from data published by the California Energy Commission.
- ° Incremental State Water Project unit energy cost computed from data provided by the Department of Water Resources Energy Division (based on coal-fired base load plants).

Annualized capital costs were also adjusted to a 7-7/8 percent discount rate and a 25-year life. The Water Factory 21 data were based on a 7 percent discount rate and a 20-year life. The Department of Water Resources estimated costs for influent pumping and injection into the ground water basin, the remaining reclamation steps.

The reverse osmosis unit at Water Factory 21, which provided the basis for this cost estimate, used a high pressure system. This system was naturally energy intensive. More recent work indicates a lower pressure system might be effective, saving considerable energy and decreasing unit fixed costs by increasing the flux rate /89./.

Because the cost of treatment will vary depending on which reverse osmosis system configuration is employed, the treatment cost estimates were expressed as a range. Table 39 summarizes the various components of the cost estimate.

Basis of Blending Water Cost Estimates

The estimated cost of blending water used in this report is based on the assumption that blending water would be of State Water Project origin and would come from future supplies. The cost estimates for future supplies of State Water Project water, presented in Table 40, indicate this water will cost from $245 to $670 per acre-foot, assuming no isolated Delta Facility is built. The estimated cost of treated water to be blended would be $120 per acre-foot. This estimate reflects costs for pumping, disinfection, carbon adsorption and regeneration, and chlorination. Based on these estimates, blended water at a blend ratio of two parts fresh water to one part reclaimed water would cost between $200 and $490 per acre-foot.

If water from another source were used for blending, the cost of the blend could be substantially different. For instance, there may be a possibility of blending existing, less expensive, water supplies to extend the existing supply.

Table 40

ALTERNATIVE FUTURE SURFACE WATER SUPPLIES
OF THE STATE WATER PROJECT

	Estimated Cost of Water Delivered to Santa Clara Valley Water District ($/acre-foot)	
Project Alternative	Assuming No Delta Facility	Assuming Isolated Delta Facility
Lake Berryessa Enlargement	245*	195
Cottonwood Creek	305**	270
Shasta Lake Enlargement	315*	245
Thomes-Newville	358**	315
Glenn	392*	300
Colusa	405**	355
Los Vaqueros	395†	395
Los Banos Grandes	400†	400
Corral Hollow	670†	670

NOTE: Cost estimates are based upon Bulletin 76-81 (Reference 87). The cost estimates appearing in the Bulletin reflect costs of delivering water to the Sacramento-San Joaquin Delta. Bulletin estimates were increased by $70 to reflect the cost of transporting the water to the South Bay Aqueduct terminal facilities of the State Water Project.

* Bulletin 76-81 figures were increased 40 percent to reflect reduced project yields if no isolated Delta Facility is built.

** Bulletin 76-81 figures were increased 17.5 percent to reflect reduced project yields if no isolated Delta Facility is built.

† Operations studies have not been performed to quantify any yield reductions that would result if no isolated Delta Facility is built. Cost estimates assume no yield reductions.

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CONVERSION FACTORS

Quantity	To Convert from Metric Unit	To Customary Unit	Multiply Metric Unit By	To Convert to Metric Unit Multiply Customary Unit By
Length	millimetres (mm)	inches (in)	0.03937	25.4
	centimetres (cm) for snow depth	inches (in)	0.3937	2.54
	metres (m)	feet (ft)	3.2808	0.3048
	kilometres (km)	miles (mi)	0.62139	1.6093
Area	square millimetres (mm^2)	square inches (in^2)	0.00155	645.16
	square metres (m^2)	square feet (ft^2)	10.764	0.092903
	hectares (ha)	acres (ac)	2.4710	0.40469
	square kilometres (km^2)	square miles (mi^2)	0.3861	2.590
Volume	litres (L)	gallons (gal)	0.26417	3.7854
	megalitres	million gallons (10^6 gal)	0.26417	3.7854
	cubic metres (m^3)	cubic feet (ft^3)	35.315	0.028317
	cubic metres (m^3)	cubic yards (yd^3)	1.308	0.76455
	cubic dekametres (dam^3)	acre-feet (ac-ft)	0.8107	1.2335
Flow	cubic metres per second (m^3/s)	cubic feet per second (ft^3/s)	35.315	0.028317
	litres per minute (L/min)	gallons per minute (gal/min)	0.26417	3.7854
	litres per day (L/day)	gallons per day (gal/day)	0.26417	3.7854
	megalitres per day (ML/day)	million gallons per day (mgd)	0.26417	3.7854
	cubic dekametres per day (dam^3/day)	acre-feet per day (ac-ft/day)	0.8107	1.2335
Mass	kilograms (kg)	pounds (lb)	2.2046	0.45359
	megagrams (Mg)	tons (short, 2,000 lb)	1.1023	0.90718
Velocity	metres per second (m/s)	feet per second (ft/s)	3.2808	0.3048
Power	kilowatts (kW)	horsepower (hp)	1.3405	0.746
Pressure	kilopascals (kPa)	pounds per square inch (psi)	0.14505	6.8948
	kilopascals (kPa)	feet head of water	0.33456	2.989
Specific Capacity	litres per minute per metre drawdown	gallons per minute per foot drawdown	0.08052	12.419
Concentration	milligrams per litre (mg/L)	parts per million (ppm)	1.0	1.0
Electrical Conductivity	microsiemens per centimetre (uS/cm)	micromhos per centimetre	1.0	1.0
Temperature	degrees Celsius (°C)	degrees Fahrenheit (°F)	(1.8 × °C)+32	(°F−32)/1.8

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